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Tree Planters' Notes

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Relationship of Filled Seed Set and Pounds of Cleaned Seed Yield per Bushel of Ponderosa Pine (*Pinus ponderosa* Dougl. ex. Laws.) Cones in the Southwest

Kenneth L. Ready

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*A cone and seed study of ponderosa pine (*Pinus ponderosa *Dougl. ex Laws. and* P. ponderosa *var.* scopulorum*) showed good correlations between filled seed set counts, filled seeds per cone, and pounds of seed yield per bushel of cones. In this study, the term* filled seed set *refers to half the number of gametophyte-filled cut seeds exposed on both faces of a cone that has been cut along its longitudinal axis.* (Tree Planters' Notes 37(1):3–4; 1986)

An average of 12,360 acres have been planted each year on national forest lands in Arizona and New Mexico from 1980 through 1984. Almost 86 percent of these acres were planted with ponderosa pine. It is therefore important to provide the best available information to cone collection planners for estimating seed yields of cone crops for this species. The most useful information is expressed in pounds of clean seed yield per bushel of cones. Such information has been limited to a range and/or average of data reported in USDA Agriculture Handbook No. 450 *(2)*. No previous work has been done to correlate an average filled seed-set count to clean seed yield per bushel of cones collected from this species. Olson and Silen *(1)* made a correlation of Douglas-fir filled seeds per cone to filled seed sets and provided data to estimate clean seed yield per bushel of cones.

Methods

Closed cones from the 1983 fall collections were cut lengthwise to expose cut seeds on each face (fig. 1). Filled cut seeds were counted on both faces and divided by 2 to determine an average seed-set count for one face. Both halves of each cone were put into a paper lunch sack. Each sack was labeled with the associated filled seed-set count. After the cones dried and opened in the sacks, seeds were extracted by peeling each scale from the fertile part of the cone axis. Dewinging was done by hand rubbing. Filled cut seeds were discarded as prerecorded data. Unfilled cut seeds were recorded. Uncut seeds were placed on a solid foundation and cracked with a small hammer. Cracked seeds were examined and recorded as filled or unfilled.

Cone lot shipments were checked at the Albuquerque Tree Nursery to verify that the number of bushels shipped agreed with Forest Service records. Twenty closed cones from each lot were cut, and filled seed sets were counted, averaged, and recorded. Normal cone drying, seed extraction, and cleaning procedures were then followed. After seed lots were dried for storage, they were weighed, counted, and recorded.

A linear regression analysis was done first to determine the relationship of filled seed-set counts to filled seeds per cone. This information was used in the following formula to estimate the number of cones in a bushel:

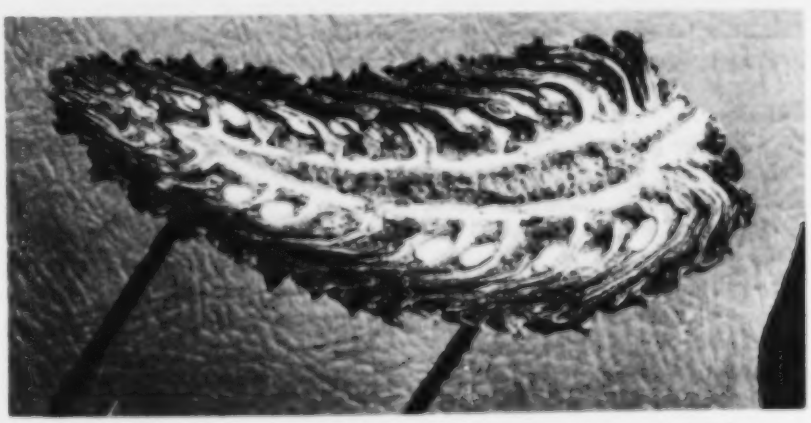

Figure 1—*Cut face of a ponderosa pine cone that had an average of 10 cut-filled seeds exposed on both faces, for a filled seed-set count of 10.*

$$C = 1/Y \times V \times N$$

where:

C = cones per bushel,
1/Y = the reciprocal of filled seeds per cone for an average filled seed-set value entered on the calculated linear regression line,
V = pounds of clean seed extracted per bushel of cones, and
N = number of clean seeds per pound.

If any estimate was less than 100 cones, or exceeded a calculated average of 255 cones per bushel by 100 cones, the nursery data were presumed to be seriously flawed by a filled seed-set sample error. An error of this nature would occur if by chance the sample was not a true representation of the cone lot. "Flawed" data were not used to calculate the linear regression line for pounds of cleaned seed yield per bushel of cones.

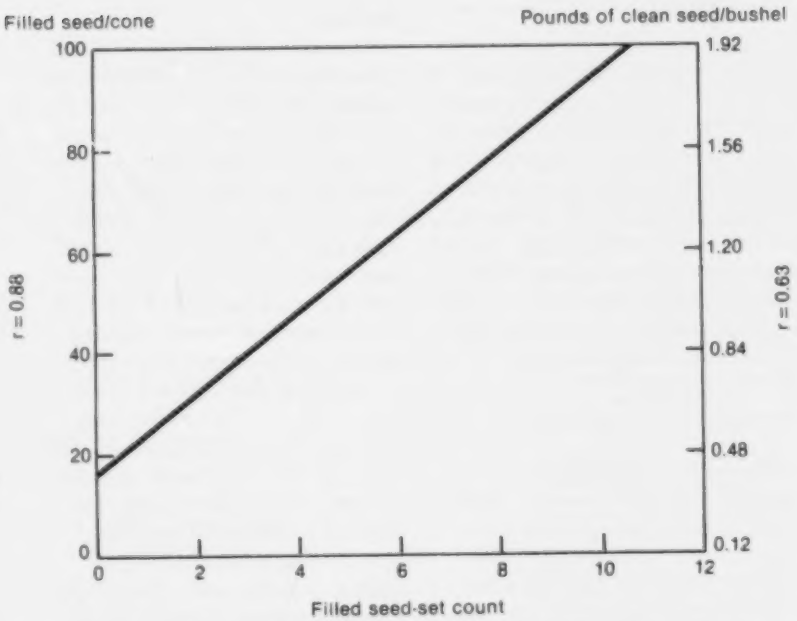

Figure 2—*Relationship of filled seed-set counts to filled seeds per cone (Y = 16.987 + 7.668X) and pounds of clean seed per bushel (Y = 0.433 + 0.137X) ponderosa pine.*

Results

Raw data from this study may be obtained by writing to the author of this paper. Filled seed-set counts and filled seeds per cone are strongly related ($r = 0.88$) (fig. 2). The relationship between filled seed-set counts to pounds of clean seed yield per bushel of cones is weaker ($r = 0.63$).

Of the 68 southwestern ponderosa pine seed lots processed at the nursery, only 8 were considered to be seriously flawed by filled seed-set sample errors. These lots showed an estimated low of 98 cones per bushel and a high of 524 cones per bushel. Eliminating these data improved the correlation by 44 percent.

Conclusions

Although the relationship between filled seed sets and pounds of clean seed yield per bushel of cones is weaker than expected, it is reliable for use and more valid than using a range or average of data from geographically different sources. Obtaining filled seed-set counts from on-going cone collection activities and applying the average to the results of this study would detect local yield variations. Cone collectors could then adjust operations accordingly.

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Nursery Application of Benomyl Fungicide for Field Control of Brown-Spot Needle Blight (*Scirrhia acicola* (Dearn.) Sigg.) on Longleaf Pine (*Pinus palustrus* Mill.)

Albert G. Kais, Charles E. Cordell, and Charles E. Affeltranger

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A benomyl fungicide treatment of longleaf pine (Pinus palustris *Mill.) seedlings generally improves field survival and significantly controls brown-spot needle blight infection.* (Tree Planters' Notes 37(1):5; 1986)

A benomyl (Benlate®) fungicide treatment of the roots of longleaf pine (*Pinus palustrus* Mill.) seedlings at the nursery during the packing operation generally improves field survival and significantly controls brown-spot needle blight caused by the fungus *Scirrhia acicola* (Dearn.) Sigg. Forest pathologists of the Southern Forest Experiment Station and Forest Pest Management (region 8) in recent cooperative studies have found the benomyl treatment to be extremely effective in every test completed to date.

Benomyl has been recently registered by the EPA as a root-dip treatment for the control of brown-spot needle blight on longleaf pine prior to packing at the nursery or at the forestation site (Supplemental Labeling EPA Reg. No. 352-354). Under this new labeling, seedling roots are prepared by dipping them in clean water and allowing excess water to drain off. Seedling roots are then covered with a benomyl–kaolinite clay mixture [1 ounce of benomyl (WP-50) and 9.5 ounces of dry kaolinite] by shaking roots for 15 to 20 seconds in a suitable container, such as a plastic bag, containing the clay mixture. This represents a dosage rate of 5 percent (wt/wt) active ingredient.

Based on these guidelines, nurseries can now treat a large number of longleaf pine seedlings with benomyl prior to packing and storing for shipment to their customers. Benomyl can also be applied by those nurseries that use a kaolinite clay mixture as the packing material for seedling storage. The benomyl–kaolinite solution in this case is made in a mixing tank by combining 50 pounds of the clay and 5.25 pounds of benomyl with enough water to obtain a solution that will adhere to the root systems of the seedlings. This benomyl–clay mixture should be sprayed on the seedlings' roots as they are packed in the shipping bags. Each nursery can modify these amounts to the capacity of its mixing tank, while maintaining the ratio of benomyl (WP-50) to kaolinite clay at 1 to 9.5, by weight.

When using the solution, several precautions should be noted: (1) Before using benomyl, read and carefully observe the cautionary statements and all other information appearing on the product label; (2) avoid applying the mixture to seedling foliage; (3) avoid exposing the roots to abnormally high temperatures (that is, above 90 °F), freezing temperatures, or to excessive drying conditions; and (4) use special care to avoid loss of the mixture from the treated roots during seedling packing, storage, transport, and field planting.

A paper summarizing all the experimental results of benomyl–clay treatment in the nursery will be published in a forthcoming issue of Tree Planters' Notes. Further information on the supplemental labeling is given in the agricultural bulletin issued by E. I. Du Pont De Nemours & Co. dated November 16, 1984, and entitled, *Supplemental Labeling, EPA Reg. 352-354, Benlate® Fungicide for Control of Brown-spot Needle Blight on Longleaf Pine*. Specifics of using benomyl on longleaf pine can be obtained from A. G. Kais, Southern Forest Experiment Station, P.O. Box 2008, GMF, Gulfport, MS 39505, phone (601) 864–8256; or C. E. Cordell, Forest Pest Management, P.O. Box 5895, Asheville, NC 28803, phone (704) 259–0643.

Tillage Superior to No-till for Establishing Hybrid Poplar Plantations[1]

Edward A. Hansen, Daniel A. Netzer, and Ruth F. Woods

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In this study on the effects of till and no-till on early survival and growth of hybrid poplar, till was always superior to no-till regardless of site, clone, or planting material. Over the three sites, tillage produced the greatest tree growth on the loam soil, the wettest and most fertile of the sites. In contrast, no-till showed its best performance on the dryer (and therefore probably warmer) sandy loam site. (Tree Planters' Notes 37(1):6–10; 1986)

Hybrid poplar (*Populus* spp.) plantations are typically established on old field sites that are heavily infested with weeds. For successful establishment of poplars, these weeds must be controlled. Site preparation and weed control are most commonly accomplished by a combination of herbicides and tillage (*3,6*). However, mechanical tillage is energy-expensive (*8*). No-till site preparation methods using herbicides alone are alternatives for possible reductions in site preparation costs. Also, no-till has the advantage of improving trafficability on wet sites. However, two plantation establishment studies using unrooted hybrid poplar cuttings as planting material have shown no-till to be inferior to tillage on imperfectly drained clay loam soils in Ontario (*9*) and on silt loam soils in Wisconsin (*4*). Both of these studies compared a range of site preparation intensities and in both cases no-till was the poorest in terms of tree growth. The no-till treatment in Ontario also resulted in poorer tree survival.

During the period these studies were in progress, the point was frequently discussed that 1 + 0 rooted hybrid poplar stock may grow as well under a no-till system as under a till system or better. No-till with 1 + 0 rooted stock is the system used by Packaging Corporation of America (PCA) for planting several thousand hectares in northern Lower Michigan. Because of the potential economic savings and increased versatility of no-till, a broader data base for comparing no-till with the more common tillage systems would be useful. So a study was begun in 1981 on PCA land near Manistee, MI, to compare the effects of till with those of no-till on early survival and growth of hybrid poplar. The study included two clones and two types of planting stock, and was installed on three different sites to check the consistency of results across soil types.

Methods

The experimental design was a split-split plot with 2 replications. Clones were the main plots, tillages the subplots, and planting stock the sub-subplots. Trees were machine planted at a 2.4- by 3.0-meter spacing with 2 rows in each sub-subplot. Rows were a minimum of 50 meters long.

The soil types consisted of a poorly drained Bergland loam developed under mixed lowland hardwoods and swamp conifers (*loam*). The area had been previously used as pasture and wild carrot (*Daucus carota* L.) predominated. A fine-clay subsoil contributed to poor drainage and formed an impermeable barrier to rooting 48 to 50 centimeters below the soil surface. (The water table was at 0.50 meter on October 28, 1981.) A second site was a well-drained Emmet sandy loam formed under sugar maple, beech, and hemlock (*sandy loam*). There were no impediments to rooting (plow pans or fine-textured layers), and the soil structure was fine granular. (The water table was at 1.7 meters on November 3, 1981.) Emmet is considered one of the best soils in the area for fruit, potatoes, and alfalfa. The site had been in pasture for several years and plant cover consisted of crownvetch (*Coronilla varia* L.) and alfalfa (*Medicago sativa* L.) The third site was an excessively drained Kalkaska sand that had not been farmed for at least 3 years before this study (*sand*). Moisture-holding capacity of this soil is poor because of its coarse texture and loose consistency throughout the deep soil profile. Sludge was applied 10 to 15 centimeters below the surface in 1978 on this latter site. Although sludge application may have raised the

[1]Funded in part by the U.S. Department of Energy Interagency Agreement DE-AI05-800R20763.

surface soil pH, it did not affect moisture-holding capacity and soil fertility.

All three sites were sprayed with glyphosate (Roundup) at 2.2 kilograms of active ingredient per hectare on October 26, and the tilled areas were plowed November 6, 1981 and disked May 15, 1982. All areas were machine planted on May 25–26, 1982. Linuron was applied over the cuttings after planting at 2.2 kilograms of active ingredient per hectare. No further treatments were applied thereafter.

Hybrid poplar clones used for the study were NE-19 *Populus nigra charkowiensis* x *P. nigra caudina* and DN-34 (*P.* x *euramericana* 'Eugenei'). Planting stock produced by the PCA nursery consisted of 1-year-old (1 + 0) bareroot stock grown from cuttings and unsoaked unrooted hardwood cuttings. Half of the hardwood cuttings were soaked, but only for 1 or 2 days; there was no noticeable soaking response and all hardwood cuttings were therefore considered as "unsoaked" in the analysis.

Tree survival and height growth were sampled by establishing a straight-line transect across the entire plot perpendicular to the treatments. Within each row, the 3 closest living trees on each side of the transect were measured. Dead trees within the group of 6 living trees were also recorded. The data were collected each fall for the 3 years following planting and were analyzed by standard ANOVA techniques. Significance was evaluated at $P = 0.05$.

Results

Mortality. Most of the mortality occurred after the first year. By the end of the third year there were significant differences in mortality within tillage treatments, planting stock types, and clones (table 1). Although mortality was 15 percent in the no-till areas and 4 percent in the tilled areas, most of the mortality in the no-till areas was associated with the unrooted planting stock. Unrooted cuttings had significantly higher mortality than rooted stock in the no-till areas (24 versus 4 percent) but only slightly higher mortality in the tilled areas (7 versus 2 percent—not significant).

Growth. Effect of tillage, planting stock, and clone on tree height was similar each year. Consequently, only the third year's data are presented.

Trees were significantly taller on tilled areas than on no-tilled areas for both clones on all three sites (table 2). Tree height averaged 2.70 meters on tilled areas and 1.86 meters on the no-till, a 45-percent difference.

There was a significant interaction of tillage with site. Tillage produced the tallest trees on the loam site. However, the best site for no-till was the sandy loam (although tillage still produced taller trees on that site).

There was also a consistent significant advantage of till over no-till regardless of the type of planting material (table 3). Unrooted cuttings were 0.78 meter (46 percent) taller with tillage than with no-till; rooted stock was 0.90 meter (50 percent) taller. Rooted stock averaged 0.45 meter tall when planted; cutting height was negligible when planted. However, DN-34 unrooted cuttings grew faster than rooted stock, so that at the end of 3 years the rooted stock was only 0.10 meter taller than the unrooted cuttings. In contrast, NE-19

Table 1—*Effect of tillage, planting stock, and clone on mortality during the first 3 years*[1]

Treatment	Mortality (percent)
Tillage	
Till	4a
No-till	15b
Planting stock	
Rooted stock	3a
Unrooted cuttings	16b
Clone	
NE-19	6a
DN-34	13b

[1]Treatments followed by different letters are significantly different from each other.

Table 2—*Effect of clone, tillage, and site on 3-year-old hybrid poplar height (m)*

Site	DN-34		NE-19		Average
	Till	No-till	Till	No-till	
Loam	2.73	1.63	4.28	2.18	2.70
Sandy loam	2.39	1.83	3.07	2.41	2.42
Sand	1.68	1.38	2.01	1.70	1.69
Average	2.27	1.61	3.12	2.10	
	1.94		2.61		

Table 3—*Effect of clone, tillage, and planting material on 3-year-old total tree height and actual shoot growth of rooted stock (m)*

Plant material	DN-34		NE-19	
	Till	No-till	Till	No-till
Unrooted cuttings	2.19	1.60	2.80	1.82
Rooted 1+0	2.35	1.63	3.43	2.36
Rooted (growth)	1.89	1.12	3.03	1.93

cuttings grew somewhat slower than rooted stock, so that at the end of 3 years the rooted stock was 0.58 meter taller than the cuttings.

There were significant differences in tree height between sites—trees on the loam site averaged 0.28 meter taller than those on the sandy loam, and 1.01 meters taller than the ones on the sand (table 4). There were also significant differences between tillage treatments, clones, and planting stock types. The best tillage practice, clone, and planting stock each individually contributed 0.84, 0.67, and 0.34 meter, respectively, to tree height. Combining the best tillage practice and clone resulted in a 1.51-meter (94 percent) height advantage over the poorest combination. And combining the best tillage practice, clone, and site resulted in a 2.90-meter or 310-percent height advantage over the poorest combination of those three variables.

A final interesting comparison is that of no-till with rooted stock versus tillage with unrooted cuttings (the major systems used by PCA and the USDA Forest Service at Rhinelander, WI, respectively) (table 4). There was only a 0.03-meter (3 percent) height advantage for the tillage and cutting system at the end of the first growing season. But by the end of 3 years, the tillage and cutting system averaged 0.50 meter (25 percent) taller than the no-till and rooted stock system.

Discussion

The poor performance of the no-till treatment in this test confirms results of earlier till and no-till site preparation trials made on an imperfectly drained clay loam soil *(9)* and on a well-drained silt loam soil *(4)*. No-till and other practices that leave plant residues on the soil surface result in higher soil moisture in the plant root zone and lower spring soil temperatures *(1)*. The moisture-retaining characteristic of no-till is an advantage on droughty soils but is a disadvantage on poorly drained soils. Agricultural studies show that tillage practices (including no-till) that leave residues on the soil surface are better adapted to the longer, warmer growing seasons in the southern half of the Corn Belt and farther south *(5)*. The fact that no-till results were best on the sandy loam, in contrast to tillage doing best on loam, suggests that the more rapidly warming sandy soils might be partially compensating for the insulating effect of no-till; and that soil temperature is indeed a negative feature of no-till.

Another potential benefit of no-till might be the improved trafficability, particularly for early spring planting. It has been argued that the earliest possible spring planting date for hybrid poplar is best. If so, no-till with its associated better trafficability could be beneficial. However, it has been shown that later planting (when soils are warmer) results in the greatest tree growth for at least the first 2 years

Table 4—*Comparison of 3-year-old hybrid poplar tree heights showing effects of several factors, singly and in various combinations**

Treatment/condition	Tree height (m)	Difference (m)	Percent difference
Site			
1. Loam	2.70a	0.28	12
Sandy Loam	2.42b		
2. Loam	2.70a	1.01	60
Sand	1.69c		
Tillage			
Till	2.70a	0.84	45
No-till	1.86b		
Clone			
NE-19	2.61a	0.67	35
DN-34	1.94b		
Planting material			
Rooted	2.44a†	0.34	16
Cuttings	2.10b		
Tillage + clone			
Till + NE-19	3.12a	1.51	94
No-till + DN-34	1.61b		
Tillage + clone + site			
Till + NE-19 + loam	4.28a	2.90	310
No-till + DN-34 + sand	1.38b		
Tillage + planting material			
Till + cuttings	2.50	0.50	25
No-till + rooted	2.00		

*Values in a treatment class followed by different letters differ significantly.
†Data shown are total height; growth was 1.99 m.

(2). In fact, because a no-till system retards soil warming, it would tend to further delay the optimum planting date. However, even though no-till and early planting result in reduced growth, early planting with no-till may still be necessary with a large operational planting program that spans many weeks. For short-duration planting programs, early planting and no-till should probably be avoided.

The type of planting stock had no effect on which site preparation method was best; tillage was always superior to no-till. However, the best type of planting material could vary with clone. Although rooted stock was the tallest at the end of 3 years for both clones, it was only marginally taller for clone DN-34. Soaking the cuttings of clone DN-34 before planting could easily cause the unrooted cuttings to surpass the rooted stock *(7)*.

Conclusions

Based on the consistently poorer results of no-till in this and other cited tests, we conclude that no-till will probably not be as suitable as other site preparation methods involving tillage at these northerly latitudes. Also, matching the best tillage practice and clone with the proper site can produce tree height several times that attained with the poorer combinations.

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Black Walnut (*Juglans nigra* L.) Establishment: Six-Year Survival and Growth of Containerized and 1+0 Seedlings

F. W. von Althen and F. A. Prince

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Outplant survival and growth of containerized black walnut (Juglans nigra *L.) was compared with that of bareroot 1+0 seedlings. Survival of containerized seedlings was significantly lower than that of 1+0 seedlings but the avoidance of outplanting shock produced a significant growth advantage for the surviving containerized seedlings.* (Tree Planters' Notes 37(1):11–14; 1986)

Black walnut (*Juglans nigra* L.) has traditionally been planted as 1+0 bareroot seedlings. However, walnut seedlings are subject to outplanting shock, which limits growth during the first year following outplanting. To determine if planting shock could be avoided and early growth increased by planting containerized seedlings, field performance of black walnut in tarpaper containers was compared with that of bareroot seedlings from the same seed source. This report presents the 6-year results.

Methods

In the autumn of 1978, black walnut seeds from selected sources in Indiana and Michigan were hulled and stratified in moist sand at 0.5 °C. In April 1979, half of the nuts were sown in a nursery and the other half were germinated in a greenhouse and sown into tarpaper containers, one nut per container. The open-ended containers, made of 19 types of commercially available tarpapers ranging in wall thickness from approximately 0.05 to 0.09 millimeter, measured 6.5 by 6.5 by 20 centimeters (fig. 1). Six of the tarpapers were formed into containers that were 6.5 by 6.5 by 30 centimeters. The growing medium was 75 percent peat and 25 percent loam without amendments.

Figure 1—*Containerized seedling at time of outplanting.*

The seedlings were grown in a greenhouse under extended photoperiods of 16 hours and a temperature of approximately 18 °C (night) and 28 °C (day). After 6 weeks the seedlings were transferred to shade frames for 2 weeks of conditioning. In the middle of June the container stock was planted by spade into well-drained loam in a fully cultivated field near Parkhill in southern Ontario. At the time of outplanting the seedlings were 20 centimeters high and actively growing (fig. 1).

In April of the following year, rows of bareroot seedling stock grown in the nursery were planted by spade between rows of containerized seedlings from the same seed sources. Of all the seedlings planted, 204 were in containers 20 centimeters high, 32 were in containers 30 centimeters high, and 271 were 1+0 nursery-grown stock.

The entire plantation was kept weed-free by annual applications of simazine (5.0 kilograms/hectare) and spot treatments of glyphosate (2.0 kilograms/hectare). The roots of each of three trees planted in containers and of three trees planted as 1+0 seedlings were excavated in the autumn of 1984, photographed, and examined for possible differences in root development. Survival and height were recorded each autumn for the first 6 years after planting, and the sixth-year survival and height data were analyzed by the Chi-square test and analysis of variance, respectively.

Results

There were no significant differences in either survival or growth of trees grown in tarpaper containers of varying thicknesses or lengths. Therefore, data from the various container treatments were combined. Six-year survival of trees planted in containers and as 1+0 nursery-grown seedlings was 87 and 94 percent, respectively, with a significant difference at

$P<0.05$. However, nearly all mortality of the containerized seedlings occurred in the year of planting and was probably related to lack of hardening off.

At the end of the sixth growing season, total heights of containerized and bareroot seedlings were 416 and 385 centimeters, respectively (table 1). The difference was statistically significant ($P = 0.05$) and was mainly the result of outplanting shock suffered by the 1 + 0 seedlings (fig. 2). There were no discernible differences in root development of the containerized and nursery-grown seedlings (fig. 3 and 4).

Table 1—*Height growth of containerized and bareroot seedlings by years from seeding*

Years from seeding	Containerized seedlings (cm)	Bareroot seedlings (cm)
1	27	33
2	54	19
3	88	70
4	67	78
5	33	44
6	147	141
Total height	416	385

Discussion

The biological advantages of containerization are well known, and black walnut seedlings have been grown in a variety of containers with different potting media, soil amendments, length of photoperiods, and other treatments to accelerate growth *(1–7)*. Most experiments have shown that early

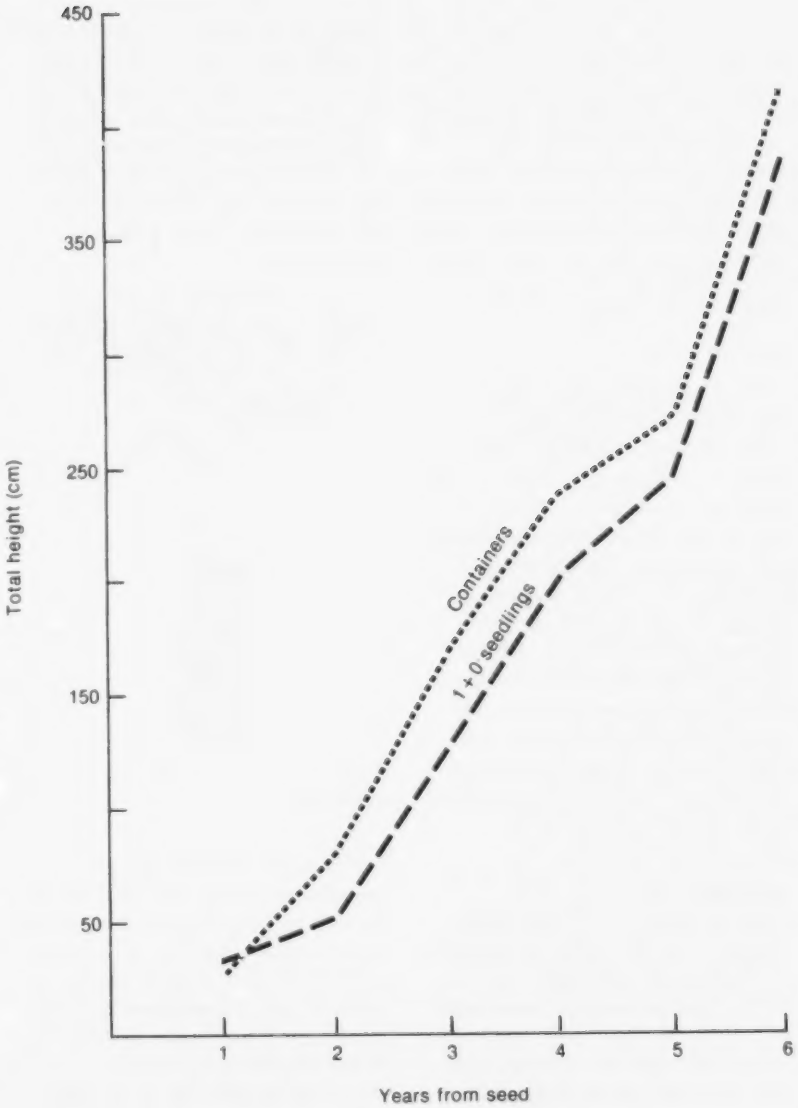

Figure 2—*Height of black walnut seedlings planted either in containers or as 1 + 0 nursery-grown seedlings.*

Figure 3—*Root form of containerized seedling.*

Figure 4—*Root form of nursery-grown seedling.*

growth can be increased by containerization, but little information is available on the field performance and extended growth of these seedlings in comparison with those of bareroot seedlings.

Black walnut seedlings require large containers to accommodate the nut, the pronounced tap root, and the large fibrous root system that develops before the fragile shoot is sufficiently hardened off to withstand injury during transport and outplanting. Wet tarpaper presented no barrier to root penetration (fig. 5). However, all root egress during the greenhouse phase was restricted to the lower half of the tarpaper cubes, which were kept wet by contact with the other cubes in the holding trays. Figure 6 shows that the roots near the soil surface have grown downward along the side of the container wall, either because they were unable to penetrate the dry tarpaper or because the root tips were air pruned.

Figure 5—*Root egress through tarpaper wall at time of outplanting.*

Conclusions

Planting black walnut seedlings in containers can be a means of avoiding outplanting shock, and growth can thereby be increased during the early years after outplanting. However, the high cost of

Figure 6—*Root system of containerized walnut seedling at time of outplanting, exposed by removal of container and washed to show root system form.*

production, transportation, and outplanting will probably restrict containerization to growing high-value seed or for use in reforestation when rapid early height growth is important to the success of the plantation.

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Effects of Root-Coating With the Polymer Waterlock on Survival and Growth of Drought-Stressed Bareroot Seedlings of White Spruce (*Picea glauca* (Moench) Voss) and Red Pine (*Pinus resinosa* Ait.)

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Root coating with a superabsorbent polymer is a recommendable precautionary measure against drought-induced mortality in areas with frequent dry spells during the planting season. Root-coated white spruce (Picea glauca *(Moench) Voss) exposed to no more then 2 weeks of post-planting drought showed a significant improvement of 24 percent in survival as compared to untreated seedlings. Root coating had not significant effect beyond 2 weeks of drought.* (Tree Planters' Notes 37(1):15–19; 1985)

Plantations established with bareroot seedlings in areas of periodic summer droughts are susceptible to increased drought-induced mortality rates *(1, 3, 5, 8, 16)*.

Improvements in survival rates and growth of newly transplanted bareroot seedlings can be achieved by modifying the plant water balance. This is done either by reducing water losses through transpiration *(4, 5, 20, 22)* or by facilitating water uptake *(14)*. The latter is accomplished when the root system is provided with a sufficient and easily tapped water supply until the plant becomes self-sustaining.

Dipping the roots of bareroot seedlings into a water-based gelatinous solution of a hygroscopic substance is a simple and inexpensive technique to provide plants with accessible water for the first critical weeks after planting *(2, 14)*. In this paper, the effect of such a treatment on survival and growth of white spruce *(Picea glauca* (Moench) Voss) and red pine *(Pinus resinosa* Ait.) bareroot seedlings are examined. Both species are widely used in reforestation programs throughout the Great Lakes region *(3, 24)*, where recurrent warm and dry spells take their toll on newly established plantations. Although root-dipping with wetting substances has been known for many years in forestry *(6)*, few critical studies have been made of the value of this treatment *(7)*. The emergence of new superabsorbent polymers with improved absorbtion and retention capabilities calls for renewed evaluations.

Materials and Methods

A complete randomized block trial was established in May of 1984 on a sandy field at the Orono Forest Station, Ontario Ministry of Natural Resources (lat. 43°58′ N., long. 78°37′ W.). Treatment combinations (species x root coating x drought level) were replicated 3 times with six plants per replicate.

The bareroot seedlings of white spruce (2 + 1) and red pine (2 + 0) were both of regional origin. The red pines were lifted in the third week of April 1984 and kept bagged in cool storage until May 9. The white spruce seedlings had been in cold storage since the end of October of 1983. Seedlings were planted manually on May 9 and were spaced at 0.3 x 0.3 meters within each plot. Initial plant sizes are listed in table 1.

Half the plants were treated immediately before planting by submerging their root system into a prepared gelatinous solution of Waterlock and water (1:160, w/w). Waterlock is a hydrolized starch polyacrylonitrile graft polymer potassium salt (Grain Processing Corp., Muscatine, IA). An average of approximately 100 grams of the gelatinous coating medium adhered to each treated plant.

Table 1—*Initial size of bareroot seedlings*[1]

	Age	Length (cm)	CV (%)	Diameter[2] (mm)	CV (%)
White spruce	2 + 1	27.3	19.1	6.2	22.5
Red pine	2 + 0	23.5	23.2	5.0	18.2

[1]CV = coefficient of variation.
[2]Measured 1 cm above the uppermost lateral root.

The drought treatments consisted of shielding the plants from natural precipitation for six different lengths of time following planting. To this end, lattice frames covered with transparent plastic foil were erected 1 meter above each plot. The slightly tilted (E–W) lattice roofs permitted passage of 50 percent of incoming radiation and had

[1]The provision of plant material, site facilities, and technical support by the Orono Forest Station (Ontario Ministry of Natural Resources) and the help of its superintendent, G. R. McLeod, are gratefully acknowledged. The Grain Processing Corp., Muscatine, IA, generously donated the polymer Waterlock used in this study.

a 30-centimeter overhang on all plot borders. Encompassing each plot, a 50-centimeter-deep ditch lined with plastic collected runoff water and prevented root outgrowth from the plots. The rain shelters were removed 1, 8, 13, 19, 27, and 34 days after planting. Bud flushing and terminal leader growth were assessed weekly on all plots during the period from May 17 to July 3.

Xylem pressure potential measurements were taken on individual fascicles for red pine and on lateral branch tips for white spruce by use of a pressure chamber and handheld lens. Precautions were observed following recommendations of Ritchie and Hinckley *(19)*. On selected days, midday xylem pressure potentials were taken on seedlings of each sample population from three additional plots established for this purpose.

All live plants were harvested on October 3, 1984, and their heights and root collar diameters recorded. Root and shoot dry matter contents were determined later. Plant dry matter was obtained after 48 hours drying at 80 °C in forced-air ovens. The significance of treatment effects (that is, root coating and drought) on dry-matter content, height, and shoot to root ratios was assessed separately for each species by means of two-way analyses of variance with frequency weighted means and interactions. Survival rates were compared on a logit-scale *(3)*. Statistical comparison of bud release and height growth was done by means of an ordinary two-sample *t*-test for grouped data *(3)*.

Results and Discussion

In treatments with less than 19 days of shielding from natural precipitation, root-coating significantly ($P = 0.05$) improved survival in white spruce seedlings by an average of 24 percent. Longer post-planting drought treatments reduced the positive effect of root-coating in white spruce to a non-significant level (table 2). The survival rates in red pine were exceptionally good regardless of treatment and were so nearly identical as to preclude any influence

Table 2—*Survival, height growth, dry matter, and shoot to root ratios of root-coated (R) and control (C) white spruce and red pine seedlings after 1 to 34 days of drought treatment (shielding from natural precipitation) after planting (May 9)*[1]

	1 day	8 days	13 days	19 days	27 days	34 days	Average
Rainfall received[2] (mm)	207	191	191	173	160	160	—
White spruce							
Survival (%)							
R	72ab*	78a*	83a*	67bc	61c	33d	66
C	60a	50b	50b	56ab	50b	39c	51
Height growth (cm)							
R	10.0a	8.3ab	7.3bc	6.7bc	5.0c	4.6	7.0
C	8.5a	8.1ab	6.8ab	7.3ab	5.4b	5.5	7.3
Dry weight (g)							
R	35.1	30.2	26.4	29.3	21.6	24.0	28.8
C	35.9	33.0	30.9	28.4	27.3	26.6	30.7
Shoot/root growth							
R	2.4	2.4	2.3	2.4	2.9	2.7	2.6
C	2.6	2.6	2.8	2.9	2.7	3.2	2.8
Red pine							
Survival (%)							
R	100a	100a	94a	94a	83b	89ab	94
C	94a	100a	94a	100a	83b	78b	92
Height growth (cm)							
R	11.5a	10.1abc	10.6ab	9.3abc	8.0bc	7.6c	9.5
C	12.9a	11.0ab	10.7ab	9.3ab	9.2b	8.4b	10.3
Dry weight (g)							
R	15.7a*	14.9a	12.5a	14.5a	10.1a	10.6a	13.0
C	20.3a	15.3b	13.2bc	10.6bc	12.1bc	9.3c	13.6
Shoot/root growth							
R	2.4b	2.6ab	3.1ab	2.9ab	3.3a	3.1ab	2.9
C	2.7b	3.0ab	3.1ab	3.1ab	3.7a	3.7a	3.2

[1]Treatment means (across rows) followed by a common letter do not differ at the 95% probability level, based on the "Studentized range" test (23).
[2]Rainfall received after removal of the rain shielding; data from the Orono Forest Station, May 9 through October 3.
*Significantly different from controls at the 95% probability level.

of root-coating (table 2). Neither species showed evidence of any simple relationship between survival and length of drought treatment. However, white spruce showed a distinct drop in survival in the longest drought treatment. The reason for the low survival rates in white spruce results from the low drought resistance of this species as compared to red pine *(15, 17)*.

Height growth was significantly influenced by root-coating. In red pine, treated seedlings showed an average of 10 percent less growth than untreated seedlings (table 2). In white spruce, root-coating promoted height growth to a slight extent in those seedlings exposed to no more than 2 weeks of post-planting drought. Reverse effects were recorded in the longer lasting drought treatments (table 2). Root-coating did not significantly affect dry-matter content.

As expected, height growth and plant dry-matter content declined significantly with progressive duration of the post-planting drought treatment *(9)*.

The ratio of shoot to root dry-matter content increased with the length of the drought period (table 2). This frequently observed reaction of drought stressed plants enhances the imbalance between water uptake and water loss through transpiration *(11–13, 21, 23)*. Root-coating, on the other hand, lowered the ratio (table 2). The lowering of the shoot to root ratio has presumably contributed to the better survival of root-coated white spruce seedlings.

Plant water potential, measured at noon on three different days during May and June, showed no effect of root-coating. However, significant differences were found between species and between days (table 3). The higher values observed in the red pine seedlings reflect the better drought tolerance of this species *(17)*. All water potential readings indicated a moderate to severe plant water stress common in transplanted seedlings at noon on warm, dry days *(9, 10)*.

In white spruce, bud release and termination of height growth occurred 2 to 3 days sooner in the coated than in the untreated seedlings. Red pine, on the other hand, displayed no influence of root-coating on flushing or termination of growth. Table 4 lists flushing stages and percentages of total height growth on selected days in May, June, and July of 1984. The data are pooled across drought treatments due to the negligible impact of drought on bud release *(18)*.

Table 3—*Midday plant water potential (MPa) of sheltered seedlings on 3 warm and dry days during the summer of 1984*[1]

Day	White spruce		Red pine		Mean
	R	C	R	C	
May 22	−1.72	−1.70	−1.15	−1.30	−1.47
June 5	−1.89	−1.81	−1.71	−1.53	−1.74
June 12	−2.14	−1.99	−1.49	−1.39	−1.75
Mean	−1.92	−1.83	−1.45	−1.41	−1.65

[1]R = root-coated seedlings, C = controls; standard error of difference = 0.1.

Summary

The effect of root-coating with the water-based, super absorbent starch polymer Waterlock on first-year survival and growth of transplanted bareroot seedlings of white spruce and red pine was assessed in a field experiment with six different periods of post-planting drought.

Root-coated white spruce exposed to no more than 2 weeks of post-planting drought showed a significant improvement of 24 percent in survival as compared to untreated seedlings. Over lengthy

Table 4—*Terminal bud release index (BRI) and percentage of total height growth (HG%) of surviving plants on different dates (May 7 to July 3) during the 1984 growing season*

Treatment[1]	May 17	May 22	May 28	June 5	June 12	June 19	June 26	July 3
White spruce								
BRI[2]								
R	0.6*	2.3*	3.8*	4.6*	5.0	—	—	—
C	0.4	1.8	3.3	4.2	5.0	—	—	—
HG%								
R	—	—	18.1*	47.9*	79.8*	85.3*	93.9	100.0
C	—	—	4.5	29.1	61.6	79.3	91.7	100.0
Red pine								
BRI[3]								
R	1.7	1.8	2.5	3.3	3.6	3.9	4.5	4.8
C	1.8	1.8	2.7	3.2	3.5	3.9	4.3	4.8
HG%								
R	—	—	—	29.4	66.5	71.6	79.7*	83.5
C	—	—	—	27.6	66.2	70.6	74.5	82.5

[1]R = root-coated seedlings, C = controls.
[2]0 = dormant, 1 = swelling, 2 = translucent bud scales, 3 = emergence of first needles, 4 = brush-like opening, and 5 = shoot elongation.
[3]0 = dormant, 1 = bud elongation, 2 = bud swelling and elongation, 3 = patchy wax deposits, 4 = emergence of short shoots, and 5 = shoot free to grow.
*Significantly different from controls at the 95% level.

periods of drought, root-coating no longer had a significant influence on the rate of survival. Survival in red pine was very high in both root-coated and untreated seedlings, with no significant effect of root-coating.

Root-coated seedlings of both species had lower shoot to root ratios than untreated seedlings, indicating comparatively better root growth.

Prolonging post-planting drought reduced growth significantly in all seedlings and increased the root to shoot ratio.

Readings of midday plant water potential showed the plants to be moderately to severely drought stressed, with no apparent effect due to root coating. Red pine had a significantly higher water potential than white spruce, indicating a better drought tolerance.

Bud release and termination of height growth occurred 2 to 3 days earlier in root-coated white spruce seedlings than in control seedlings. No such differentiation was observed in red pine.

It is concluded that root-coating with a superabsorbent polymer is a recommended precautionary measure against drought-induced mortality in areas with frequent dry spells in the planting season.

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Time of Germination: A Factor in Rate of Growth of Accelerated Transplants of Black Spruce (*Picea mariana* (Mill) B.S.P.)

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Cotyledonous black spruce (Picea mariana *(Mill) B.S.P.) seedlings, initiated in "cigarette" germination plugs, were planted in peat cubes over a range of dates in the greenhouse. Following midsummer transplanting, bareroot trees were sampled in the fall of each production year. Rate of growth through the first and second year in the nursery is related to time of germination. Second-year growth is related to size of stock after the first season in transplant beds. Rate of growth in terms of daily dry weight increment was found to be related to time of germination through both the first and second seasons in the nursery. Second-year growth was also related to stock size at the end of the first season.* (Tree Planters' Notes 37(1):20–24; 1986)

In a 2-year bareroot transplant system for black spruce (*Picea mariana* (Mill) B.S.P.), uniform early germination and rapid early growth are essential. The size of transplants after one and two seasons in nursery beds varied directly with the duration of growing period since the time of germination *(6)*. The results were attributed primarily to an extended growing season.

An additional factor is the rapid growth achieved through the season by plants from early germinated seedlings. In an accelerated transplant system, that is, greenhouse-initiated seedlings for transplanting as eventual bareroot shipping stock, time and space are important considerations in both quality and cost of seedlings. Pregermination of seed may save several days of greenhouse operations and ensure full initial stocking of uniformly developed plants.

This report relates rate of growth in terms of plant *dry weight* production and time of germination in a 2-year accelerated transplant system.

Methods and Materials

Mean plant data—root collar diameter, plant height, oven-dry weight of roots and shoots, and shoot to root ratio—have been published *(6)*. Total plant dry-weight data are presented here in relation to the duration of growth during the two growing seasons.

Stratified seed was sown in "cigarette" plugs of commercial peat moss rolled with cellulose tea bag material for "paper" *(6)*. Seed was germinated under optimum conditions recommended by Fraser *(1)*. After they shed their seed coats, the cotyledonous seedlings were planted in peat cubes 2.5 centimeters square and grown in a greenhouse for 6 to 14 weeks (depending on date of germination), and then removed for 2 weeks of conditioning. Plants were transplanted in July of 1975 by hand in normal nursery beds at Orono Forest Station, Orono, ON (lat. 43°59' N. long. 78°37' W.).

Seed were germinated over a range of dates from February 15 to June 11. From 400 to 3,000 cotyledonous seedlings were planted at each sowing time and grown in trays of approximately 400 cubes each. Trees of each tray, identified by time of planting, formed separate plots in the nursery bed. The stock was treated according to standard nursery procedures through the remainder of 1975 and 1976.

Samples were lifted in the fall of each production year; about 20 bareroot transplants were taken in a line across each bed. For each assessment, measurements of height and root collar diameter were made on each tree. Roots were separated from tops at the root collar. Both were oven dried at 105 °C for 24 hours to determine the mean dry weights of plant samples.

Results

First-year growth in terms of total plant ovendry weight is represented by the slope of lines from date of sowing to weight of 1-year-old plants harvested in the fall of the first season in the nursery (fig. 1). Germinants from successive sowings exhibited lower rates of increase in plant dry weight.

In the second season, all plants experienced a full growing season from flushing in May to lifting of samples in November. Growth through the season exhibited similar relationships of increase in dry weight relative to germination date in the first year (fig. 2).

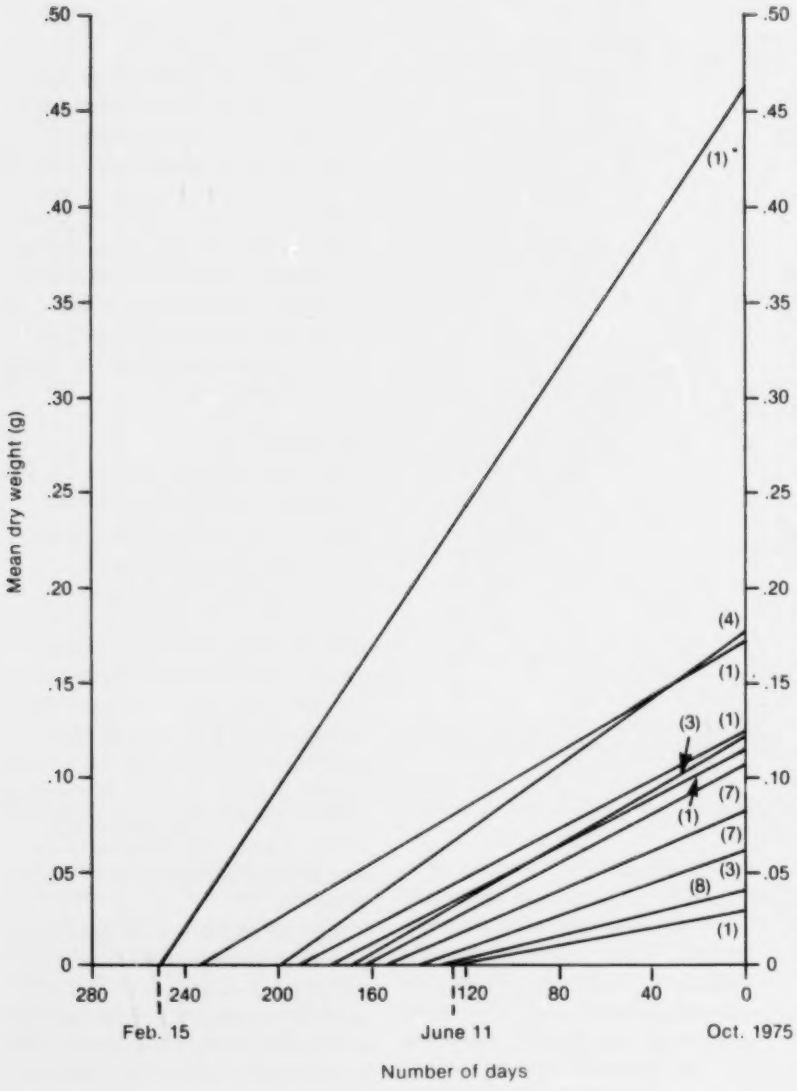

Figure 1—*First-year mean plant dry weight (g) related to duration of growing season in days prior to fall sampling. Numbers in parenthesis indicate number of 20-tree samples included in data.*

A first-year growth rate per day was calculated for each of 37 samples (table 1). First-year dry plant matter production (*Y*), measured in milligrams per day, correlated highly ($r = 0.834$) with time, in days, from germination to sampling (*X*), using the equation $Y = -0.912 + 0.009X$ (fig. 3). The equation accounted for 69.9 percent of the variability in average growth rate. Mean daily growth rates through the first season varied from 0.24 milligram per day for seedlings germinated in June to 1.85 milligrams per day for those germinated in February (table 1).

Similarly, daily growth in the second year, calculated as second-year minus first-year mean dry weight over 180 days for the 36 samples available in the second year, correlated highly with total growing time over the 2 years ($Y = -40.095 + 0.150X$), accounting for 70 percent of growth variability ($r = 0.837$) (fig. 3). Second-year growth increments varied from 5.25 milligrams per day for plants from late germination in the first year to 27.00 milligrams per day for plants from earliest germination, associated with cumulative duration of growth of 308 to 432 days, respectively.

Second-year dry-weight increment also correlated highly with first-year mean plant dry weight ($r = 0.820$). The equation $Y = 1.061 + 9.595X$, where *Y* is total dry-weight increment and *X* is dry weight of 1-year-old plants, accounted for 67.2 percent of the

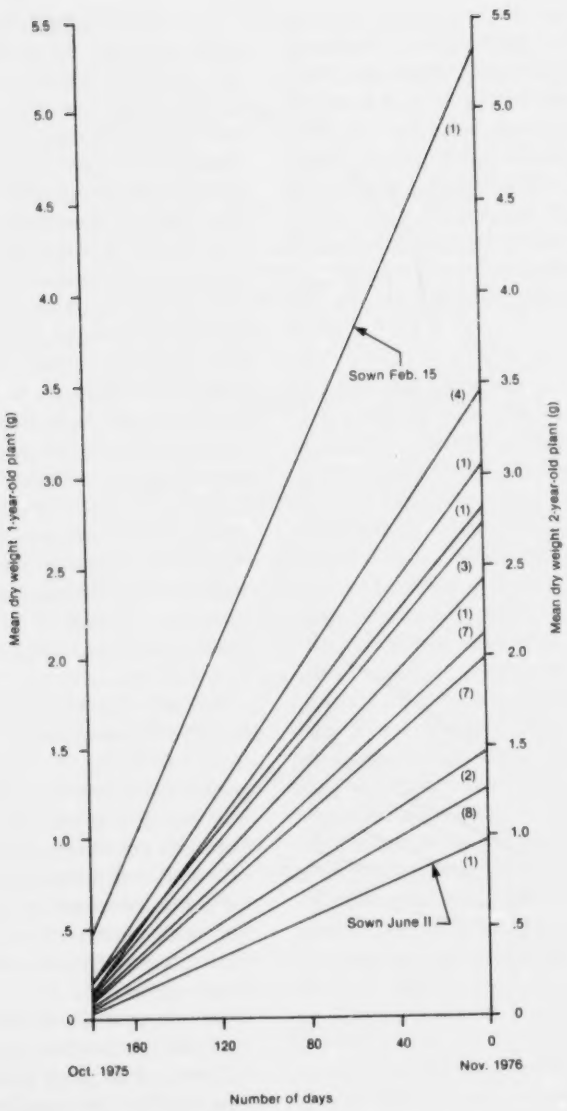

Figure 2—*Second-year mean plant dry weight (g) related to duration of growing season in days prior to fall sampling. Numbers in parentheses indicate number of 20-tree samples included in data.*

variability in mean second-year growth.

In each of the regressions, second- and third-order relationships were tested. In some instances these explained somewhat more of the variability in data. However these regressions were considered to be unduly influenced by limited information in the early weeks of the study. Therefore the linear regressions noted above were considered more appropriate for analysis of results.

Discussion

First-year growth of black spruce in nursery beds was not proportional to duration of growing season alone. Plants from seed germinated in February grew at mean daily rates that were five to eight times those of plants germinated in late May to early June. This increase was associated with a 100-percent increase in duration of growing season. During the second season, a three- to fivefold increase in daily growth was associated with a 40-percent increase in cumulative duration of growth over 2 years.

Scarratt and Reese *(5)* published growth progressions for jack pine (*Pinus banksiana* Lamb.) container stock to establish the time required to produce shippable stock for different sowing dates. Their data indicated faster rates of growth for seedlings that were germinated early. In fact, their oven-dry weight for 3- to 4-month-old first-year jack pine sown early exceeded that of

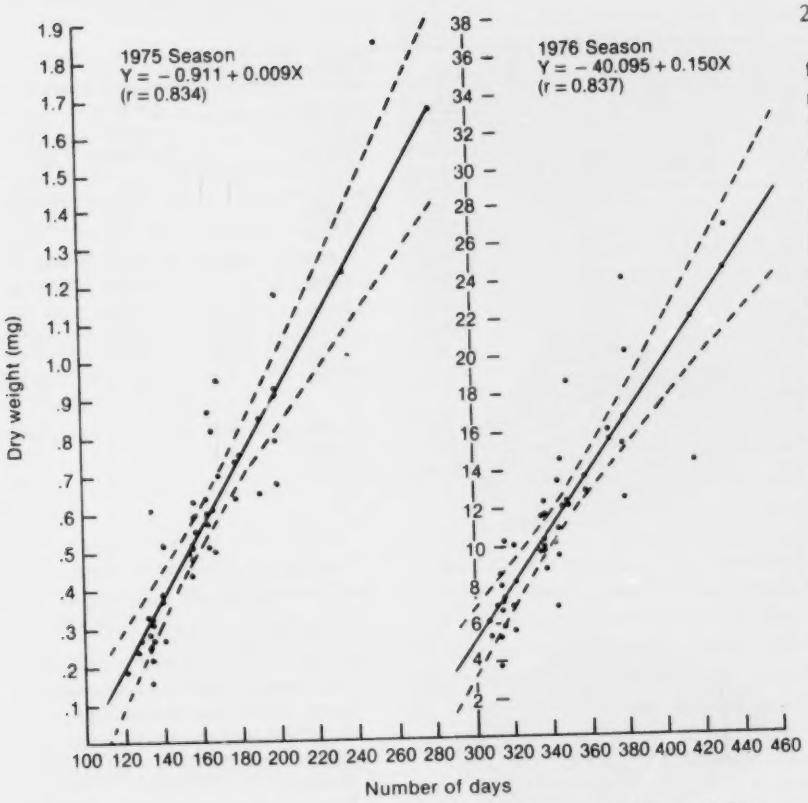

Figure 3—*Mean daily growth (mg) related to duration of growing season (days) with 95 percent confidence limits (2).*

overwintered 2-year-old plants sown late in the first year. Similar growth predictions have been developed for container stock of other species.* Hallett *(3)* showed different growth patterns for fall-sown black spruce container stock than for stock sown in the early spring.

*Sadreika, V. Forestry Resources Bureau, Ontario Ministry of Natural Resources, Toronto (personal communication).

Second-year growth of black spruce transplants in this study was directly proportional to size of plant at the end of the first season. June germinants grew into 1-gram plants in 2 years whereas February germinants weighed 0.5 gram at the end of the first season and 5 grams after the second season. Factors influencing the size of 1-year-old plants apparently have an important influence on the quality of 2-year-old bareroot shipping stock.

One important component contributing to early vigor is pregermination of seed. If seed are germinated before they are planted in the greenhouse, plants can take full advantage of the growing degree days during the early part of the growing season, when growth is most vigorous. The time saved depends on the pregermination system employed. Use of day-old germinants saves up to a week of greenhouse time; use of cotyledonous seedlings or young trees may save from 4 to 8 weeks. Germination of seed and early plant development can be accomplished in a fraction of the space required for later plant growth. Use of pregerminant seed or cotyledonous seedlings planted in a greenhouse production system produce better stocking.

A heated greenhouse provides an advantage in terms of growing degree-days over a "Finn house" in which auxiliary heat is provided only to prevent freezing. Insulated plastic nursery bed shelters *(7)* provide less of an advantage in terms of growing conditions but represent lower capital costs and no cost of heat energy. In each case, sowing pregerminated seed provides more uniform plant development and full initial stocking.

The influence of first-year plant size on rate of subsequent growth is a factor to be considered in production of other stock products. In container production, valuable

Table 1—*Daily rates of growth relative to date of sowing*

		First-year assessment (1975)				Second-year assessment (1976)				
Sowing date	No. of trays	Length season (days)	Mean plant dry wt (g)	SD	Daily growth (mg)	Cum. length 2 seasons* (days)	Mean plant dry wt (g)	SD	2nd year growth increment (g)	Daily growth (mg)
Feb 15	1	252	0.465	—	1.85	432	5.325	—	4.860	27.00
Mar 2	1	234	.172	—	0.74	414	2.798	—	2.626	14.59
Apr 1/2	4	199	.178	0.043	0.89	379	3.429	0.891	3.251	18.06
Apr 9	1	191	.124	—	0.65	371	3.033	—	2.909	16.16
Apr 22	1	178	.114	—	0.64	358	2.418	—	2.304	12.80
May 1	3	169	.121	.039	0.72	349	2.713	.703	2.592	14.40
May 5/7	7	164	.107	.023	0.65	344	2.108	.483	2.001	11.12
May 13/15	7	156	.083	.010	0.53	336	1.993	.226	1.910	10.61
May 27	3	141	.055	.018	0.39					
	2					321	1.466	.576	1.411	7.84
Jun 4/7	8	134	.041	.018	0.31	314	1.254	.346	1.213	6.74
Jun 11	1	128	.031	—	0.24	308	.976	—	.934	5.25

*Duration of 1975 season + 180 days in 1976.

greenhouse space is often used for two or more changes at different times in the season. Little is known of the effect of time of germination on vigor of outplanted trees. Similarly, production of seedling stock is based on variable germination times through the first season in nursery beds. Later germinants with reduced vigor and a shorter growing season produce smaller 1-year-old plants. This contributes to the variability common in beds of black spruce and adds to the reduced yield and increased cost due to culling.

In the 2-year accelerated transplant system for black spruce described here, trees from early sowings grew to a size comparable to 3-year-old bareroot nursery stock standards in Ontario (*4*). Rapid early growth due to early germination formed a major component of this success. Pregermination of seed is one economical means of improving on germination time in this or any stock system, thereby reducing the space and heating energy required for growth during the coldest period in the production schedule.

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Cutting Stratified Seed of Western White Pine (*Pinus monticola* Dougl. ex D. Don) To Determine Viability or To Increase Germination

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*Ungerminated, but viable, stratified western white pine (*Pinus monticola *Dougl. ex D. Don) seed will germinate after the side of the seed is cut, exposing the gametophytic tissue. Germination of stratified but uncut seed from several trees averaged 21 percent, ranging from 10 to 30 percent. Germination of stratified and cut seed from the same trees averaged 80 percent, ranging from 20 to 93 percent.* Tree Planters' Notes 37(1):25–26; 1986

Germination of western white pine seeds is often slow and erratic, even after the recommended stratification procedures (90 to 100 days, with constant moisture at 3 °C) are followed (*2*). Consequently, one is left wondering if the seed was viable, or if something went wrong with the stratification treatment.

In some of our earlier work, we have induced germination of seed that had been stratified and sown by cutting a small sliver from one side of the seed. Poor germination of a recent test made it necessary to cut seed to improve germination. The purpose of this note is to share this procedure with others.

The seed is cut along one side of the seed to remove a small sliver of the seed coat, membrane, and gametophytic tissue (fig. 1). One-sixteenth of an inch can be cut carefully from the radicle end of the seed. A cut at the opposite end results in abnormal germination; namely, the cotyledons emerge through the cut end. Also, the cut must pierce the membrane between the seed coat and gametophytic tissue, or germination will not occur. The membrane, which consists of the inner layer of cells of the integument, appears to the critical structure restricting or preventing germination for this type of dormancy.

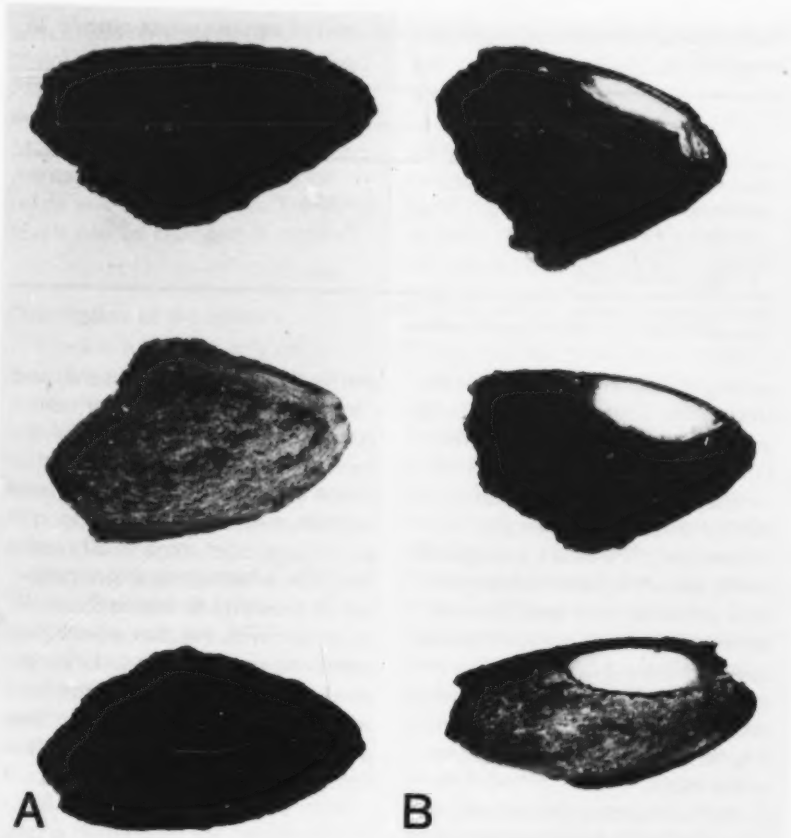

Figure 1A—*Intact seed.* **B**—*Seed cut on side; notice that cut is made into gametophyte tissue.*

One hundred and seventy-five seed from 35 seed lots were sown on May 2 in 10-cubic-inch containers. The seed had been given 45 days of cold-wet stratification. (*1*). After 28 days of incubation in a warm (70 °F) greenhouse, only 31 percent of the seed germinated (table 1). Therefore, we dug up an

Table 1—*Germination of intact and cut seed of western white pine in 35 seed lots*

	Germination	
	No	%
Intact seed (6125 seed sown, 175/lot)		
28 days of incubation	1,928	31
49 days of incubation	2,107	43[a]
Cut seed (37/lot)[b]		
21 days of incubation	906	71

[a]Total seed adjusted by seed cut, i.e., 6125 − 1270 = 4855.
[b]Intact seed were cut 23, 24, and 25 days after incubation.

average of 37 seed per lot, cut the seed on the side as indicated in figure 1, and replanted them in the same container. After 21 days of incubation, average germination of the cut seed was 71 percent. Meanwhile, 179 intact seed germinated, which equaled 43 percent after adjusting total seed for number of seed cut. Some seed lots responded more than others. For example, 90 percent of the seed of one seed lot germinated after cutting, compared to only 1 percent when intact.

With the cutting procedure, one can readily determine viability and germinability of stratified seed, and can thus assign the cause of nongermination either to poor quality seed or to the failure of the stratification procedure to overcome seed dormancy factors. The number of germinants from some small seedlots from which a minimum number of seedlings is required can be increased with this procedure. Because the procedure is so labor-intensive, it would probably not be economical for large-scale use, but a mechanical device might be developed to accomplish the task.

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A Soil Moisture Control System for Greenhouse Plant Stress Studies

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A greenhouse soil moisture control system for imposing stress levels is described. Moisture stress in this system results from opposing tensions between a moisture source and a vacuum pump and evapotranspiration. Tree Planters' Notes 37(1):27–32; 1986

In greenhouse experiments investigating competition among plant genotypes, plants are generally exposed to different levels of nutrients and allelopathic phytochemicals. Because nutrient availability and the effects of phytotoxins depend on the availability of soil water, control of soil water or moisture stress is imperative. This paper describes a tension lysimeter system designed to maintain two predetermined levels of negative pressure on a soil supporting a large number of seedlings. In this system, soil moisture content is controlled by a balance between evapotranspiration and a vacuum imposed through a ceramic cup in the bottom of the soil profile and moisture moving in response to tension through another ceramic cup in the center of the soil profile. Buffer tanks are used to maintain static tension and to minimize vacuum surges. The system insures drainage in the bottom of planting chambers and serves as a supplementary watering system.

As tested, the system supplied between 45 and 75 percent of total water requirements needed to maintain −0.05 and −0.01 megaPascals (0.5 and 0.1 bars, respectively) soil moisture stress levels. Modifications to decrease supplementary watering can easily be made and are described. The stress levels can be changed as needed.

Description of the System

Tension lysimeters rely on a moisture gradient for movement of water through the soil profile. The moisture gradient in this system results from opposing tensions between a moisture source and an imposed vacuum and evapotranspiration.

The system consists of a series of 32 experimental chambers in a greenhouse with partial environmental control (fig. 1). Each chamber measures 61 by 61 by 61 centimeters (outside dimension) constructed with 1.9-centimeter-thick plywood; it has rabbeted, caulked, and cross-screwed joints, and is painted on the inside with a roofing compound to prevent leakage (fig. 2). The floor of each chamber is recessed 1 centimeter into the sides and sloped 2.54 centimeters to minimize stagnation in the bottom of the box. The chambers are placed on 7.6- by 8.9-centimeter frames that are 1.3 centimeters higher on the side perpendicular to the 4 percent slope of the chamber floor; the result is that one corner of each chamber may serve as a point of moisture accumulation, although accumulation would not be expected at these soil water contents except during wetting-in.

A standard 1.3-centimeter CPVC (chlorinated polyvinyl chloride) male pipe adaptor is used as a bulkhead union in the lower corner of each chamber; a 2.23-centimeter-outside diameter (o.d.) ceramic cup (0.1 megaPascal, standard flow, Soil Moisture Equipment Corp. No. 655X1-B1M1; 1 megaPascal = 10 bars) is attached to the inside and is closed with a rubber stopper on the outside. One end of a length of plastic laboratory tubing (Nalgene) (0.64 centimeter o.d. by 0.8-centimeter wall thickness) is inserted through the rubber stopper with the other end of the tubing connected to a 1-liter drainage bottle placed horizontally next to the base of each chamber; a second tube in this bottle is connected to a vacuum manifold. The vacuum creates a negative pressure in each bottle. This vacuum controls the soil moisture tension in each corresponding chamber (fig. 2).

The negative head pressure in the bottle is also used to control the watering system. A third tube connects each horizontal bottle with a water-filled bottle hanging upside down over each chamber; the vacuum head pressure tube in the hanging bottle must be above the fluid level of the water supply. Another tube from each hanging bottle is connected to a rubber stopper in a 46-centimeter-long, 3.8-centimeter-o.d., schedule 40

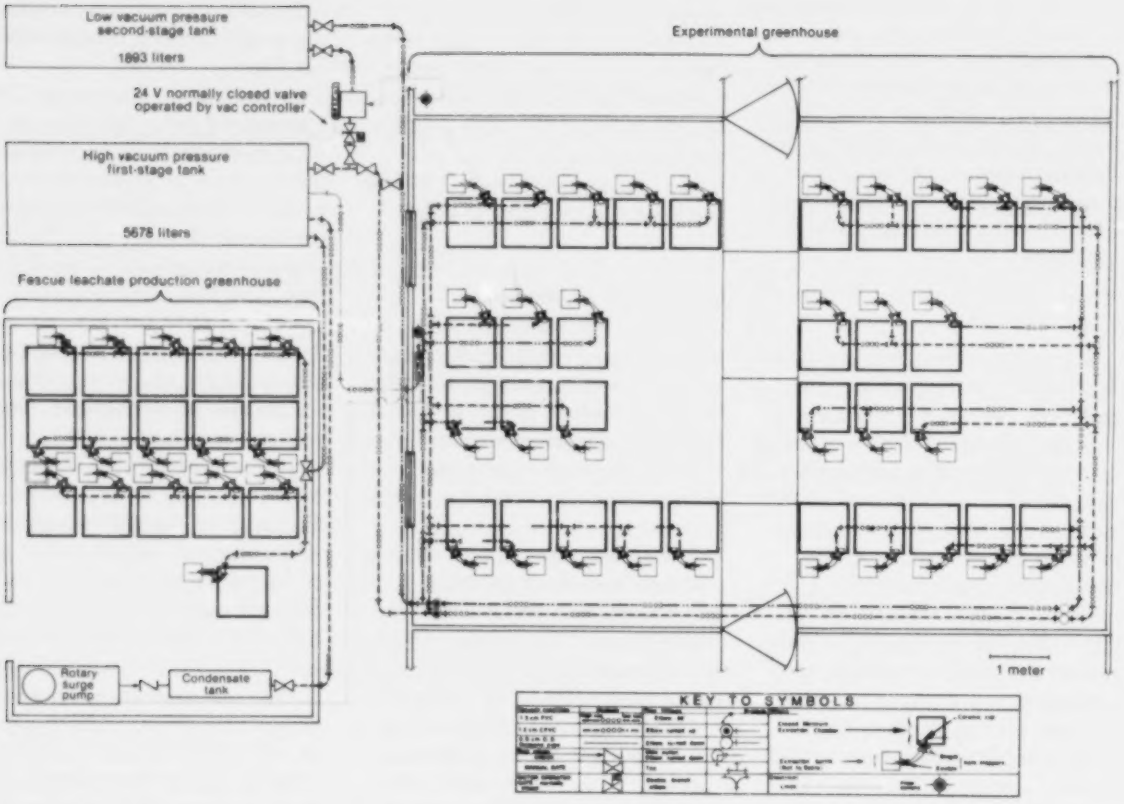

Figure 1—*Schematic diagram of chambers and soil moisture control system. (The fescue leachate production greenhouse on the left was part of another experiment.)*

PVC (polyvinyl chloride) pipe with a 5.2-centimeter-o.d., 0.05-mega-Pascal-tension, high-flow porous ceramic cup (Soil Moisture Equipment Corp. No. 653X3-B.5M2) on the other end (fig. 2). The pipe with the ceramic cup is inserted into the soil at a 45° angle to insure the vertical collapse of the soil on the ceramic cup after the soil is watered-in; a hole of an appropriate size must be evacuated in the soil and some fine silica (particle size $\leq$ 250 µm) added to this hole before the pipe and its ceramic cup are positioned in the soil.

When properly positioned, this ceramic cup is approximately in the center of the soil profile in each chamber. Water enters the soil through this ceramic cup when the moisture tension in the soil increases beyond that imposed by the smaller ceramic cup in the bottom of the chamber. Therefore, the moisture content of the soil is governed by a balance between the vacuum imposed in the bottom of the chamber and/or evapotranspiration and the moisture provided by the ceramic cup in the center of the soil (fig. 2).

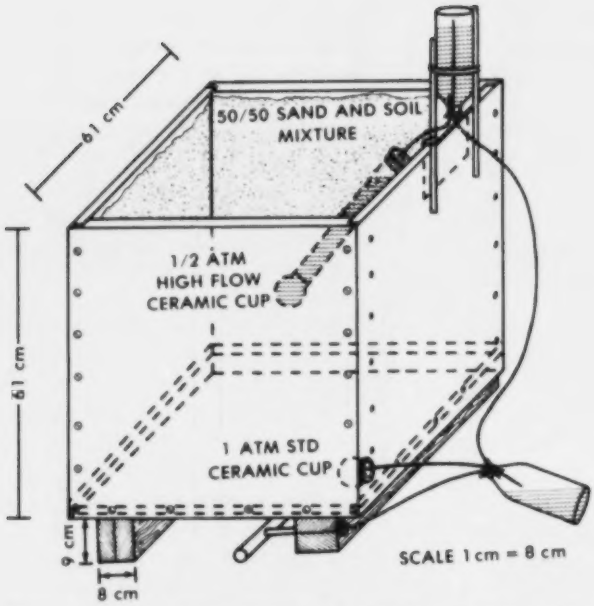

Figure 2—*Diagram of experimental chamber with moisture control system.*

The desired moisture stress is created by means of a rotary vacuum pump. We used a Surge Alamo Model 20 (566 liters per minute, 20 cubic feet per minute), which is commonly used by the dairy industry. In our system two stress levels were imposed, −0.05 and −0.01 megaPascals. The vacuum pressure levels are regulated by electrical vacuum controllers attached to buffer tanks; both vacuum controllers are 24-volt diaphragm microswitches (fig. 3). The purpose of the buffer tanks is to create a large enough vacuum reservoir to keep a static tension on the moisture system with a minimum of vacuum surges. The high stress–high vacuum level results from a direct connection between a 5678-liter (1600-gallon) tank (approved by the American Society of Mechanical Engineers, or ASME) and the vacuum pump. The diaphragm microswitch attached to this tank normally remains open and is activated by a drop in vacuum in the tank. The low stress–low vacuum level is maintained by a second–stage 24-volt controller which regulates an in-line solenoid value between the first- and second-stage buffer tanks. The switch normally remains closed. The second-stage tank has a 1892-liter (500-gallon) capacity and is also approved by the ASME (fig. 2).

Each buffer tank is attached to a PVC feeder line [inside diameter (i.d.) 1.7 centimeters]; feeder lines are in turn attached to CPVC manifolds (i.d., 1.2 centimeters) distributing the vacuum to experimental chambers. A third tank, in-line between the first-stage buffer tank and the vacuum pump, forms a condensate trap to prevent moisture from entering the pump (fig 2).

The soil used to fill the chambers was a uniform 1 to 1 mixture (by volume) of silty clay loam and medium-textured river sand. The sand was used to reduce the moisture gradient in the soil profile. Before the chambers were filled with the soil mix, approximately 0.7 kilogram of fine silica was placed around the small ceramic cups in the bottom of each chamber. The silica maintains continuity of capillary action between the soil and the ceramic cups. The soil in the chambers was watered-in from above over a 1-week period until field capacity was attained.

The effectiveness of the moisture control system was evaluated by weighing the soil-filled chambers biweekly. At the beginning of the experiment each chamber contained 256 kilograms of soil mix at 16 percent moisture content (on a dry-weight basis). Changes in chamber weight were attributed to soil moisture content changes and seedling growth. Because total seedling weight per chamber after one season's growth was negligible relative to the weight of the soil,

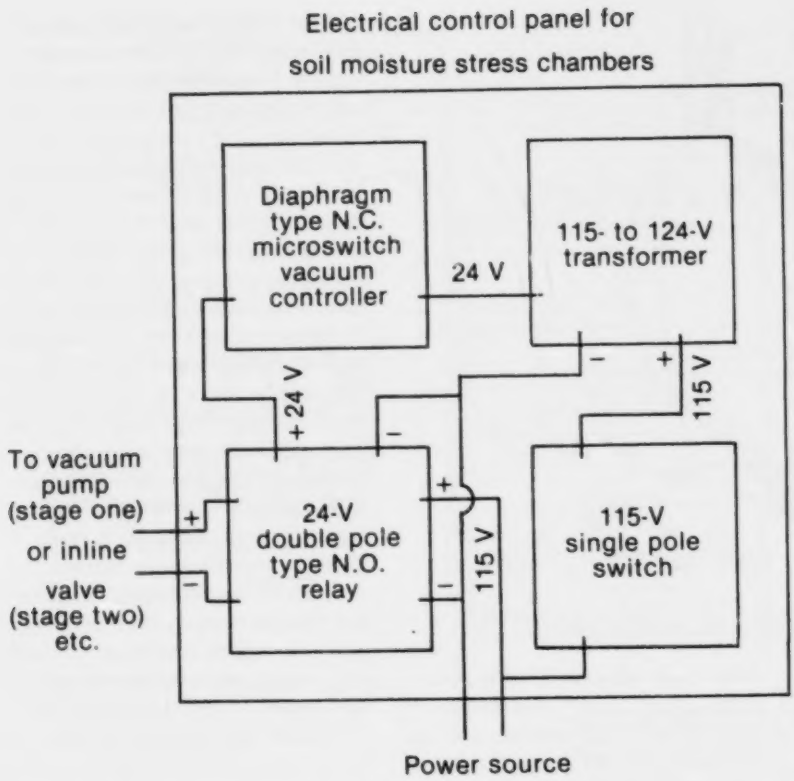

Figure 3—*Electrical control panel for soil moisture stress chambers.*

all weight changes were attributed to moisture content.

A steel cradle for lifting, moving, and weighing the soil-filled chambers was built with 5.0-centimeter-o.d. square steel tubing with 3.176-millimeter wall thickness; within the cradle a steel yoke supports two chain harnesses that can be attached to the chamber (fig. 4). The chambers are weighed by attaching an electronic transducer load cell (W. C. Dillon and Co. Model Z, 454-kilogram capacity, ± 0.23-kilogram accuracy) between the yoke and the cradle.

Performance of the System

The main objective of this system was to maintain differences between two soil moisture stress treatments. This was done by applying −0.01 and −0.05 megaPascal of vacuum tension to the soils in the low-stress and high-stress treatment chambers, respectively. The chambers contained black walnut seedling planted as germinating seed in April and grown for 20 weeks through August 1983. Measurements began approximately 1 month after planting.

Stress levels resulted in average total evapotranspirational water losses of 37.1 liters per chamber in the −0.01 megaPascal treatments and 13.5 liters per chamber in the −0.05 megaPascal treatments for the 4-month measurement period with 30 black walnut seedlings per chamber. Because the low-stress treatment also resulted in substantially faster growth (seedlings growing in the low-stress treatment were 48 centimeters in total height and 13 grams dry weight after 20 weeks versus 36 centimeters in height and 7 grams dry weight in the high-stress treatment), the three-fold difference in water loss also reflects greater transpiration rates on the part of the larger seedlings.

Analysis of variance of percentage of soil moisture (dry-weight basis) disclosed statistically significant differences between the two moisture stress regimes for all measurement periods (table 1). Although the differences in percentage of soil moisture declined until June 28, the minimal difference in soil moisture content between the two moisture regimes at this time (0.58 percent) is within the expectations of a sandy loam soil at these stress levels (*1*). In a sample of noncompacted soil subjected to the pres-

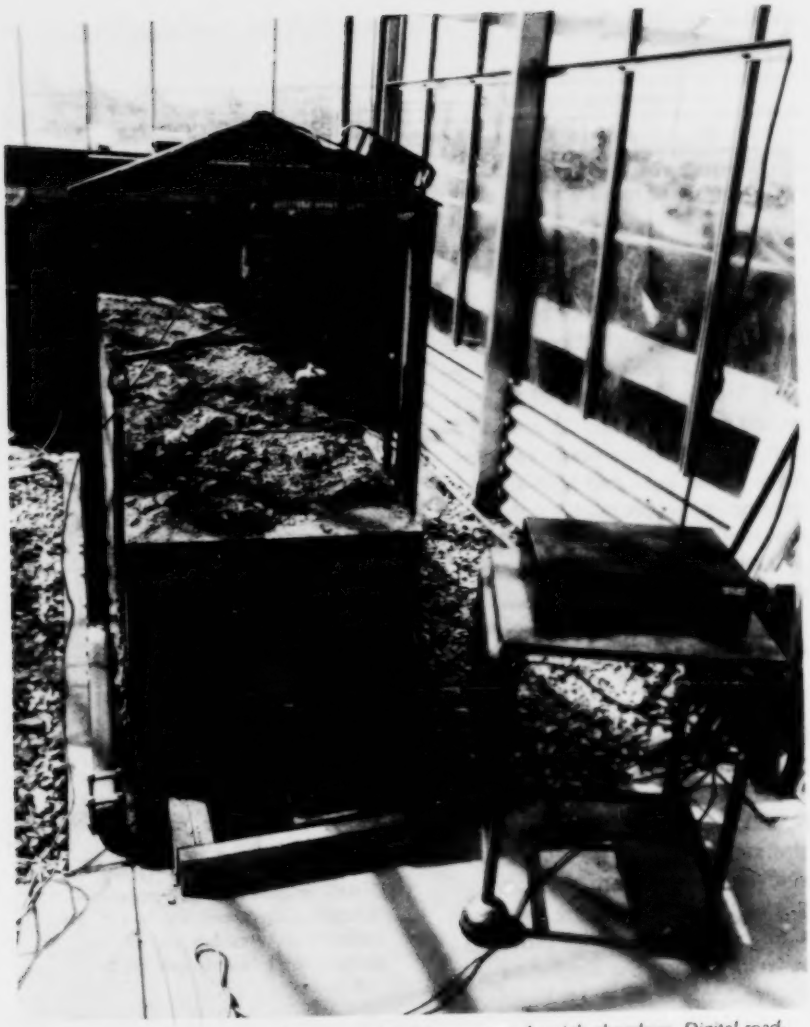

Figure 4—*Cradle, yoke, and harness used to lift, move, and weigh chambers. Digital readout is pictured to the right of the chamber.*

sure plate extraction method, the difference in moisture content between soil under −0.05 megaPascal of tension and that at −0.01 megaPascal was 1.7 percent (see chart at right), a value comparable to the differences measured at the beginning of the study.

Negative pressures (MPa)	Soil moisture (%)
−0.01	15.87
− .03	14.56
− .05	14.18
− .10	14.06
− .50	4.47
−1.00	4.35
−1.50	3.80

In addition, standard deviations around average soil moisture contents per chamber indicate that moisture distribution between chambers was relatively uniform (table 1). Increases in the difference in moisture content between the two stress regimes beyond June 28 are the result of supplementary watering of low-stress treatment chambers to alleviate unexpectedly high evapotranspiration rates encountered at this time. The high evapotranspiration rates resulted from a combination of larger seedlings transpiring greater quantities of water and record high temperatures in the summer of 1983.

The soil in the chambers developed a dry hard crust approximately 2.5 centimeters thick; beneath this surface crust, soil moisture was apparently uniformly distributed. No moisture had stagnated in the chamber bottoms. Because the walnut seedlings were removed from the chambers with intact roots, there was ample opportunity to observe the direction of root growth. There was no indication of root growth toward the center of the chamber (the location of the ceramic cup that was the

Table 1—*Average percentage of soil moisture per chamber and standard deviation (SD), on a dry-weight basis, for six measurement periods*

	Percentage soil moisture (ave. ± SD)					
Stress level	May 17	June 2	June 14	June 28	July 26	Aug 9
Low (−0.01 MPa)	15.54 ± 0.47	12.90 ± 0.80	10.87 ± 0.91	9.13 ± 0.70	7.55 ± 0.75	9.23 ± 0.72
High (−0.05 MPa)	13.96 ± 0.35	11.80 ± 0.64	10.10 ± 0.74	8.55 ± 0.73	6.65 ± 0.84	6.23 ± 0.74
Differences	1.58	1.10	0.76	0.58	0.90	2.91

water source); thus, we assumed that the moisture permeated the soil uniformly by means of capillary action. Similarly, there was no evidence of faster growth of walnut seedlings in the center of the chambers in contrast to seedlings located in other parts of the chambers.

As stated earlier, the moisture control system provided an average of 37.1 and 13.5 liters per chamber of water in the low- and high-moisture-stress treatments, respectively. Although this was adequate to maintain moisture stress differences between the two treatments, it is evident from table 1 that, due to evapotranspiration, absolute stress levels exceeded the −0.01- and −0.05-megaPascal values imposed by the vacuum system. In order to maintain those absolute stress levels, we would have needed to add a total of 13.6 and 16.4 liters per chamber of water to each low- and high-stress chamber over the 20-week experimental period. The moisture control system would have provided 73 and 45 percent of the total water requirement of the low- and high-stress treatments, respectively, if the system had been designed to maintain −0.01 and −0.05 megaPascal of absolute moisture stress.

Conclusion and Recommendations

In summary, the moisture control system described here maintained soil moisture differences between the two stress treatments and provided drainage to prevent stagnation in the chambers. The system also supplied between 73 and 45 percent of the watering requirements; the total watering requirement could probably be provided by a) increasing the size of the water supply bottles and b) providing another ceramic cup in each soil profile. This would increase the efficiency of the system, which depends on the size and number of ceramic cups providing water as well as soil texture, volume, and rate of evapotranspiration. Such systems may be of interest to other researchers dealing with greenhouse experiments in which soil environment must be controlled.

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Richard F. Camp

Cover: Six-month-old paulownia seedling at the Western Maryland Research and Education Center, Keedysville. (Photo courtesy of Dr. John F. Kundt, Department of Horticulture, University of Maryland.)

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Propagation of Eucalyptus Nursery Seedlings

Lee O. Hunt and Robert S. Logan

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The very small size of eucalyptus seed, along with accompanying contaminants, makes them difficult to handle and stratify. A simple method of stratifying and propagating eucalyptus from seed is described and illustrated. Tree Planters' Notes 37(2):3–7; 1986.

Most eucalyptus nursery stock in the United States is produced as container seedlings. Although Hunt (2) has reported some comparative trials between bareroot and container outplanted seedlings, most commercial and public agency nurseries use some form of container.

The seeds of all species of eucalyptus are very small and generally mixed with the chaff from the inside of the seed capsule (figure 1). It is difficult to separate the seed from chaff because of their similar sizes and weights. This creates problems in using any kind of seeding equipment to discharge 1, 2, or 3 seeds per container opening or at a predetermined spacing in a nursery bed. Thus, common practice is to broadcast seed in trays, then pick out the small germinants and transplant them into containers. These are then grown for one season before being planted out in the field.

Another problem involves the need for moist stratification of some seeds, not only for some species but also for some provenances of a single species. Doran and Gunn (1) reported that seed of *Euc. glaucescens Maid. & Blakeley.* (Tingiringi gum) from the Mt. Tingiringi provenance requires no stratification.

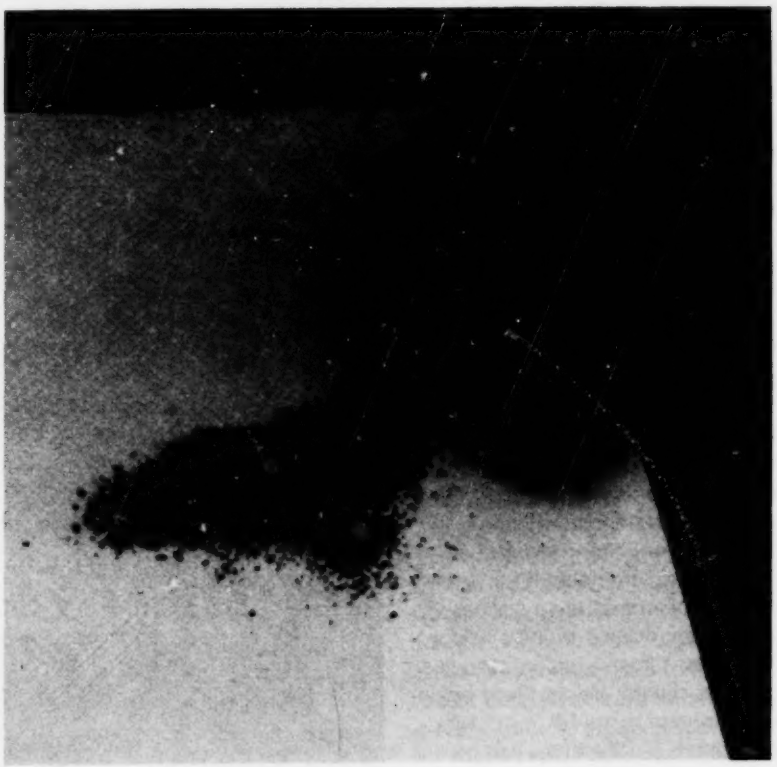

Figure 1—*The small* Eucalyptus urnigera *seed mixed with the trash of the seed capsule.*

Germination rate and number of seedlings for the Tinderry Range provenance are significantly increased by a 14-day cold moist stratification. Seed from the Guthega, Mt. Erica, and Mt. St. Gwinear provenances of this species need a pretreatment cold moist stratification of 42 days. This influence of cold on germination is of particular interest to those attempting to grow eucalyptus in areas of considerable winter frosts. Doran and Gunn report that *E. glaucescens* is one of the most cold tolerant of the eucalyptus.

Attempts to give eucalyptus seed the usual stratification by soaking them in water, then refrigerating them, results in a gooey mess that is almost impossible to handle. It was due to this situation that an alternate procedure was developed.

Methods of Stratification and Seeding

Because of the very rapid growth of both roots and tops of seedlings, we use Tinus Rootrainer book-type containers. We use a commercial potting medium (W. F. Grace Company forestry mix).

The Tinus containers are arranged in boxes and filled with the forestry mix. A small pinch of eucalyptus seed is placed in each book cell opening (figure 2), then dusted with 5 percent captan and covered lightly with the potting mix and quartz ("chicken grit," No. 2) rock (figure 3). These boxes of seeded containers are then set outside in the open midwinter (December through January) and allowed to stratify naturally (figure 4). The mean minimum temperature during these 2 months in our southwest Oregon region averages 34 °F or slightly below. Seed begin to germinate by mid-April to May first (figure 5). Seedlings can be grown for 1 year before being planted out in the field (figures 6 and 7).

There are numerous species of eucalyptus that require no stratification. However, there is a dearth of information on specific requirements for seed from various provenances. Thus, all species that have been used in our screening program for cold tolerance have been treated in the above manner. No definitive data are given on germination because there is no simple,

Figure 2—*Placing a small pinch of seed into the opening of Tinus Rootrainer plastic containers.*

Figure 3—*Dusting seed with 5 percent captan prior to covering with potting mix and "chicken grit." Containers on the left show the "chicken grit"—No. 2 quartz rock—used to protect the seed.*

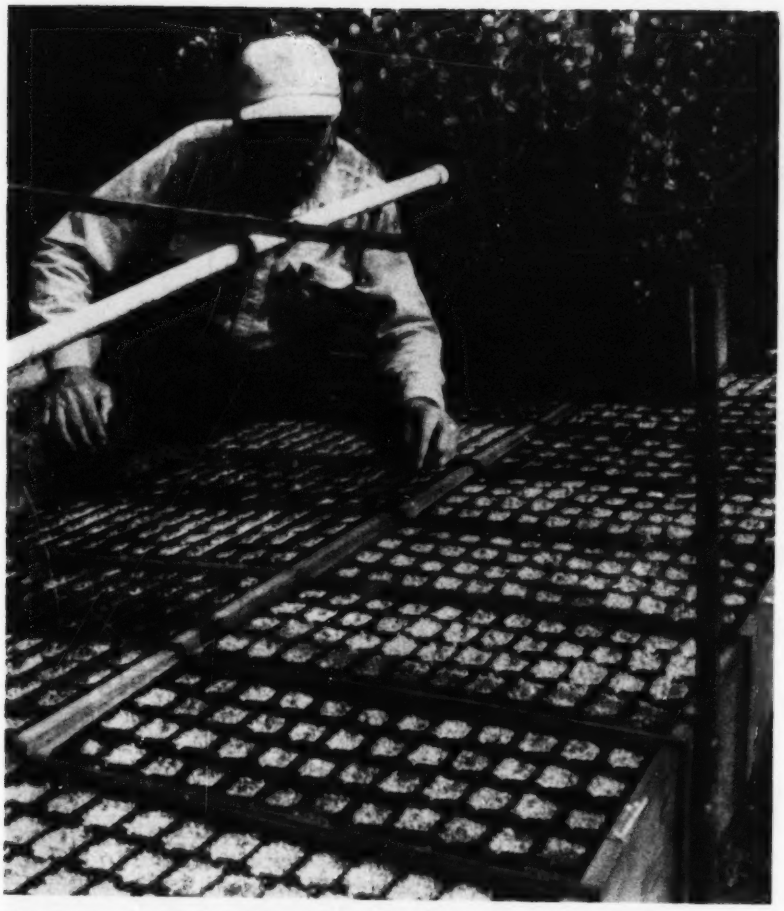

Figure 4—*Boxes of seeded containers set outside for natural stratification and germination.*

economic way to count the number of seeds placed in each container opening. The seed and chaff particles in some species are so similar as to be largely indistinguishable. Excess seedlings in container openings are plucked out. Transplanting some of them into vacant openings has been only partially successful.

Areas with subtropical or at least more moderate winter temperatures could use the same procedure. Seed can be watered and stored in the containers in boxes or trays and placed in a cold storage room at 32 to 38 °F for the required stratification period.

Advantages of this simple procedure include 1) only dry materials are handled, 2) no second handling of the seed in the stratification process is needed, and 3) the germinants do not need to be transplanted from trays to containers. Some two dozen species of eucalyptus have been grown successfully with the procedure during the past decade of our screening trials for cold tolerance.

Figure 5—*Emerging seedling in late April.*

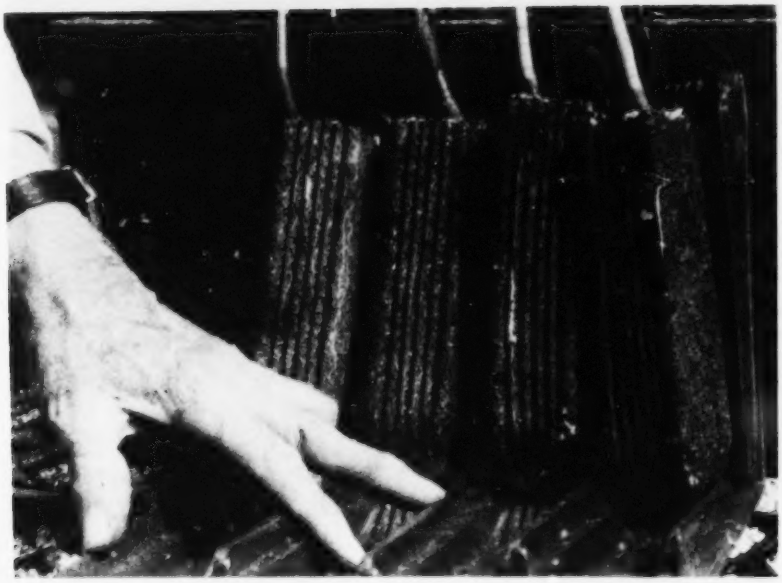

Figure 6—*Opened-up book of Tinus container showing rooting ball of 1-year-old seedlings.*

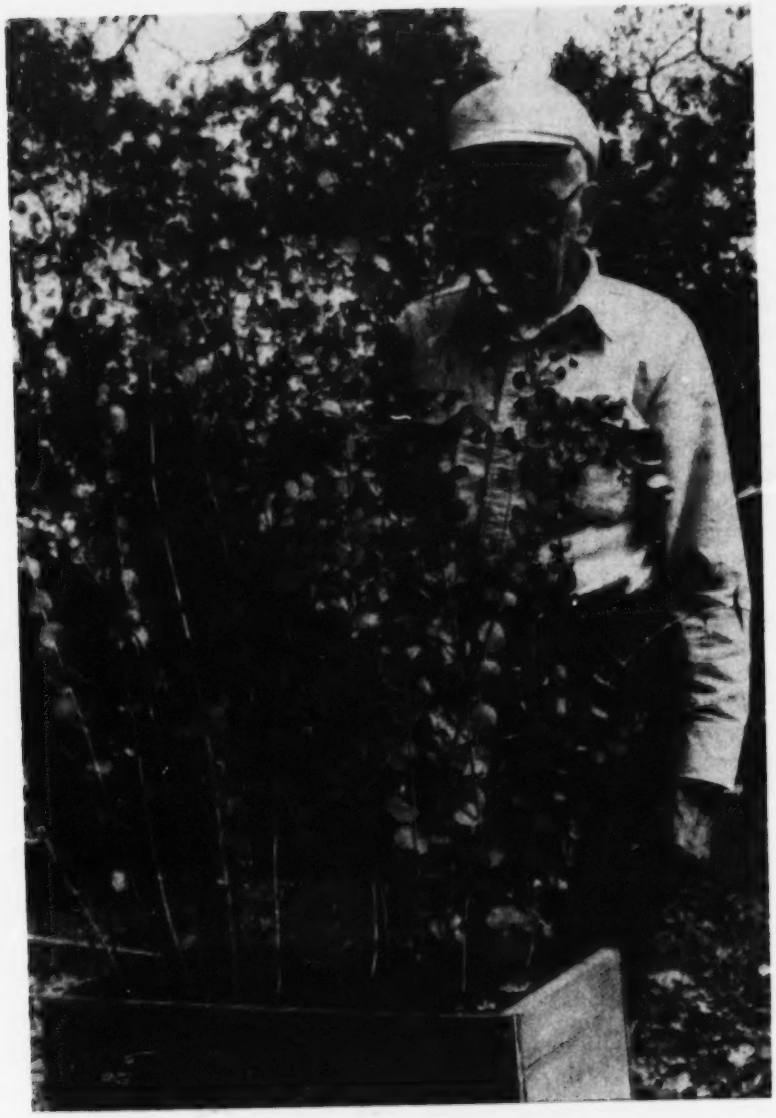

Figure 7—*One-year-old seedlings of Urnigera gum* (Eucalyptus urnigera) *in specially made nursery boxes.*

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A Practical Method for Production of *Paulownia tomentosa*[1]

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A practical method for producing Paulownia tomentosa *planting stock in the nursery is presented. The maximum mean seedling height (85 centimeters) was obtained from seedlings thinned to 20 per square meter, and the maximum root collar diameter (1.6 centimeters) was obtained from seedlings thinned to 10 per square meter. Unthinned beds yielded 200 to 300 seedlings per square meter with an overall mean height of 37 centimeters and a mean root collar diameter of 0.4 centimeter.* Tree Planters' Notes 37(2):8–11; 1986.

Expectations of significant returns from exports of *Paulownia tomentosa* logs cut from naturalized trees have spurred interest in its cultivation. Experimentation and planting trials were initiated in the 1970's by several private entrepreneurs as well as researchers at the University of Kentucky to determine the suitability of paulownia as a high-value species for surface mine reforestation (*3,7*). As paulownia exports increased, the potential of planting specifically for timber production gained widespread publicity (*6*). During this time researchers worked at developing techniques for storing and germinating seed, seedling production, and outplanting (*1,4*). Unfortunately most of the successful methods developed for producing planting stock incorporated greenhouses or other facilities not normally available for widespread use. The utilization of artificial environments raised the cost of seedlings far above the costs of most other tree species ($0.55 per seedling). These costly methods were used because many of our normal nursery practices led to total failures or at best sporadic successes when applied to paulownia. To date, even nursery practices developed specifically for paulownia have proved less than adequate (*1*). Because of these failures, it became increasingly apparent that new tactics were needed if a successful means of producing low-cost paulownia planting stock was to be established.

In 1981 a study was initiated to determine a practical method of producing various types of paulownia planting stock. The study was undertaken with the premise that the methods and equipment utilized would allow not only tree nurseries but many landowners to produce their own planting stock. The search for a successful procedure meeting the above criteria led to the incorporation of a technique commonly used by tobacco farmers in the southeastern United States. Tobacco seed are very small, as are paulownia seed, and many of the same problems are encountered in nursery bed production of both species. A summary of successful procedures derived from this study is given below. Specific study methods and results will also be discussed.

Procedures

The procedures outlined here are general guidelines for nursery bed production of paulownia planting stock. Individual situations may necessitate minor changes or additions to these procedures; however, the techniques employed for germinating the seed should produce adequate results over a wide geographical range.

Nursery beds should be located in areas with good drainage. Maintenance of sandy or heavy loam soil is imperative, for the young plants are susceptible to waterlogging. A minimum soil porosity of 50 percent, with a noncapillary porosity of at least 10 percent is recommended (*8*). Soil pH should be maintained between 5 and 8. Avoid locating beds in frost pockets. Early autumn frosts can injure the succulent foliage of this plant, and extreme winter cold can lead to root collar wounding and rootstock mortality.

The beds should be cultivated in early spring and covered with clear plastic (4 mil). Methyl bromide should be applied to kill unwanted seeds, nematodes, and fungi harbored in the soil. After the danger of frost has passed, the plastic can be removed and fungicide (such as

[1]The research reported in this paper was supported by the McIntire-Stennis Cooperative Forest Research Program. The paper is publication 85-8-107 of the Kentucky Agricultural Experiment Station.
[2]The author thanks Bert Marshall for his assistance in caring for the plant beds.

captan 50 W) incorporated to a depth of 10 to 15 centimeters. The beds should be raked to produce a relatively smooth surface. Fertilizer should also be applied at this time. Detailed fertilizer requirements are not known for *Paulownia tomentosa;* however, the need for certain micronutrients has been expressed by several workers. The following fertilizer regime proved successful under our soil and climatic conditions: a slow-release NPK fertilizer such as Osmocote (14-14-14) at 400 grams per square meter, a slow-release micronutrient additive such as Micromax at 80 grams per square meter, and gypsum and dolomite at 200 grams per square meter each. A single fertilizer application should be sufficient for the entire growing season and should not produce any significant problems with the dormant or germinating seeds. After the beds are moistened, seeding can be undertaken at a rate of approximately 0.2 gram per square meter. Scattering the seed can best be accomplished by hand on a windless day.

Maintenance of a moist environment during germination and initial seedling development is one of the most important steps for ensuring successful germination and establishment. Desiccation for even short periods can be fatal during the early development of the radicle. Desiccation of radicles has been observed between irrigations during afternoons when temperatures were high and relative humidities were low. The small seeds on the soil surface are able to support only one attempt at radicle emersion, making the microenvironment surrounding the seed critical. A soil amendment, mulch, or a covering over the bed is necessary to maintain an adequate moisture regime. Trials with soil amendment or mulch have led to sporadic results. This is due to movement of the mulch, amendment, and/or seed by wind or by the direct impact of water from precipitation and irrigation.

Maintenance of the proper environment, while avoiding the problems mentioned above, can be accomplished by covering the nursery bed with a spunbonded polyester or nylon canvas, commonly known as a "tobacco plant bed cover" (figure 1). This covering suspended above the bed allows light, which is necessary for paulownia seed germination, to filter through while alleviating the adverse effects of water and wind. The covering disperses the incoming water droplets, allowing only a fine mist to reach the soil surface and provides a warm, moist, and undisturbed environment at the soil surface (figure 1). This type of covering is used extensively in the United States for growing tobacco transplants. Light-weight cotton or cheesecloth could also be used, but the synthetic material is much less expensive and readily avail-

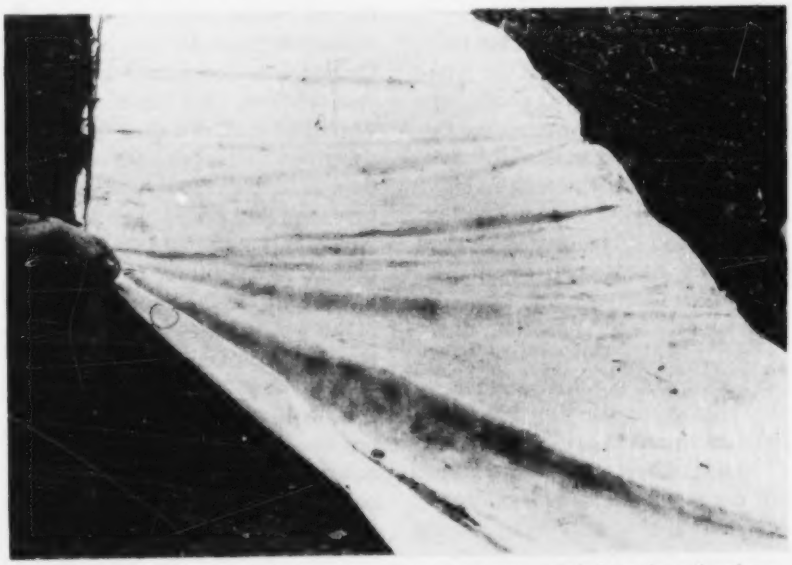

Figure 1—*Paulownia plant bed with tobacco plant cover suspended above the soil surface. Seedlings are less than 1 centimeter high.*

able. The covering can be suspended over the soil surface by a series of arched wires placed along the center line of the bed, by attaching it to a wooden frame surrounding the plant bed, or by a very small amount of straw spread over the soil. If the covering is allowed to contact the soil the plants will grow through the cover and it will not be possible to remove the cover without damaging the seedlings. The covering can be removed when the seedlings average 4 to 8 centimeters in height.

Seedling density is important in producing good planting stock. Thinning should be completed when plants average 20 centimeters in height. Postponing the thinning leads to small spindly plants. Thinning is necessary for proper development, but the specific level depends upon the type of planting stock being produced. Thinning is best accomplished by hand, leaving the most vigorous seedlings intact. Thinning levels will be discussed in a later section.

Overhead irrigation can be used to ensure maintenance of a moist seed bed. Overwatering, however, can quickly lead to seedling decline. Irrigation should be reduced in September. Normally, either entire root systems or root cuttings should be used as planting stock. The use of bareroot seedlings is not recommended. Leaves should be allowed to abscise prior to pruning the main stem at the groundline. Rootstocks should overwinter in the beds, covered with 5 cm of a mulch such as sawdust. Mulch is necessary when ground temperatures are expected to fall below 0 °C. The rootstocks can be outplanted in the spring or allowed to grow a second year in the nursery bed or moved to a transplant bed to produce 2–0 or 1–1 planting stock, respectively. A good review of handling procedures for paulownia planting stock is given by Kundt (5).

Study Methods

The 1.2- by 15.2-meter beds were elevated 20 centimeters above groundline and were composed of equal parts sand, topsoil, and sawdust. In mid-April the beds were covered with 4-mil-thick plastic and treated with methyl bromide (two 1-pound cans of Brom-O-Gas). One week later the plastic was removed. Fertilizer and seed were then scattered over the bed as described in the procedures section. A supplemental fungicide treatment was not applied in 1981. However, captan 50 W was incorporated to a depth of 10 to 15 centimeters in 1982. The seeding rate of 0.2 grams per square meter equaled approximately one-half cup for the 1.2- by 15.2-meter bed. In 1981 three-quarters of the bed was covered with a spunbonded polyester canvas suspended approximately 2 to 10 centimeters above the bed surface, and the remainder left uncovered. Overhead irrigation was necessarily increased on the uncovered portion of the bed.

In 1982 four thinning treatments were applied when mean seedling height was 20 centimeters. Various portions of the bed were hand thinned, leaving 10, 20, and 100 seedlings per square meter, and an unthinned control. Total height and root collar diameters were measured at the end of the growing season.

Results and Discussion

1981. The seeds in the uncovered portion of the bed failed to germinate or were desiccated after germination even though they were irrigated daily. The direct impact of water droplets from both precipitation and irrigation allowed much of the seed to be washed into concentrated areas or buried by the shifting soil. Seed burial resulted in reduced germination by decreasing the level of light reaching the seeds to below that necessary for germination.

The covered portion of the bed produced approximately 300 plants per square meter with a mean height of 30 centimeters. However, over the course of the growing season, the seedlings stagnated and portions of the bed exhibited dieback. Pathological investigation identified a root decay fungus (*Rhizoctonia* sp.) and an anthracnose fungus (*Colletotrichum* sp.). Therefore, the initial methyl bromide treatment was supplemented with captan 50 W in 1982 to provide

continued protection against fungal invasion.

1982. The thinned seedlings had increased height and root collar diameters compared with the unthinned seedlings (table 1). The unthinned treatment yielded approximately 200 seedlings per square meter with a mean height of 37 centimeters and a mean root collar diameter of 0.4 centimeter. There was no dieback in the unthinned treatment as in 1981, possibly due to the increased protection afforded by captan 50 W. Root collar diameters and observed root sizes were inversely related to seedling density. Between the thinned treatments, diameters ranged from 0.5 centimeter (100 per square meter) to 1.6 centimeters (10 per square centimeter). Average height ranged from 85 to 61 centimeters for the 20 and 100 seedlings per square meter treatments. The 20 seedlings per square meter treatment also produced the smallest range (10 centimeters) in seedling height.

The thinning level selected depends upon the type of planting stock required. A thinning level with a high residual density can be employed if 1–0 or 1–1 seedlings or rootstocks are to be outplanted. However, if 2–0 stock is being produced, one of the heavier thinning levels should be utilized. Subsequent thinnings may also be necessary if 2–0 stock is being produced. Regardless of the planting stock being produced, tops of seedlings should be pruned at groundline for outplanting as well as for increasing winter survival.

Table 1—*Response of* Paulownia tomentosa *to various thinning levels*

	10/m²	20/m²	100/m²	Unthinned
Mean height (cm)	76	85	61	37
Range height (cm)	63–92	81–91	52–65	21–63
Root collar diameter (cm)	1.6	1.1	0.5	0.4

Conclusions

Although establishing *Paulownia* plantations is still a popular idea, past planting failures have caused many to become disillusioned with the species. As with any new species, it will take time to successfully determine all the techniques necessary for plantation culture. However, the procedures outlined in this article should help to rectify some of the problems normally encountered during seed germination and planting stock production. Beckjord (2) has compiled further information on plantation culture; however, it must be realized that the cultivation of paulownia is a recent phenomenon in the United States and only long-term results will determine the effectiveness of our current recommendations.

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Improved Handtools for Site Preparation

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Manual site preparation will continue to play an important role in reforestation efforts in the years ahead. New, more efficient handtools are now available that can make this labor-intensive, expensive task more cost effective. Tree Planters' Notes 37(2):12–14; 1986.

Hand scalping for site preparation before planting trees is a common practice in reforestation. Hand scalping is labor intensive and expensive, but it is well suited for steep slopes. Production rates are usually low, but workers are able to select the most favorable microsites for the tree seedlings.

Our contacts with land managers indicate that hand scalping will continue and may even increase as timber harvesting moves to steeper sites that make mechanical site preparation more difficult or impossible.

Because hand scalping will continue to play an important role in reforestation efforts in the foreseeable future, Forest Service Timber Management asked the Missoula Equipment Development Center (MEDC) to undertake a search for more efficient and effective handtools that would help reduce hand scalping costs.

Initial investigation uncovered a unique handtool that had been developed by Gordon Reinhart, a Forest Service fire management officer on the Umatilla National Forest in Pendleton, OR. This tool, known as the Reinhart grubbing tool, was developed initially for fireline construction but is also used for scalping. A tool that can quickly and efficiently scrape away vegetation to mineral soil to build fireline is also a good tool for site preparation. Reinhart's grubbing tool was constructed using a fire shovel and reversing a shortened blade and replacing the shovel handle with an adze handle (figure 1).

Joe Bruzda, a former Forest Service employee, redesigned the Reinhart grubbing tool and began manufacturing his version under the name Fyr-Tamer (figure 2).

Figure 1—*Reinhart grubbing tool.*

Figure 2—*Fyr-Tamer.*

To determine how scalping tools like the Reinhart grubbing tool and the Fyr-Tamer compared to conventional tools for site preparation and fireline construction, MEDC conducted two evaluations.

In the first, the Reinhart, Fyr-Tamer, and a tool built by MEDC called the modified Reinhart (figure 3) were sent to Forest Service planting crews on ranger districts in four western regions for evaluation. The Reinhart was modified by using an entrenching toolhead with a number 0 shovel blade welded to it and replacing the handle with an adze hoe handle.

Responses to all the tools were favorable. Most crew members preferred these tools to those they had been using. Increases in production of up to 30 percent were reported.

In the second evaluation, Center personnel compared these three new tools with the adze hoe, Pulaski, super Pulaski, and McLeod for performance and human energy cost efficiency. The results indicated that the Reinhart, modified Reinhart, and Fyr-Tamer are as efficient or more so than these conventional tools for digging fireline.

The evaluation further suggested that although the three new tools were efficient, they did not represent the optimum design possible. Field users had identified some deficiencies in the tools. As a result, MEDC designed a "combination" tool (figure 4) that corrected these shortcomings with a longer handle and a blade that had a more modified curve to increase efficiency and production.

A followup field evaluation of this "combi" tool indicated it is much closer to an optimum design for a scalping tool. The Center worked with a toolmaker to refine the design for actual production. Manufacturing specifications were written and 300 "combi" tools were produced for fireline construction evaluations during the

Figure 3—*Modified Reinhart grubbing tool.*

Figure 4—*Combination tool.*

1985 fire season. This tool should be available from the General Services Administration by the spring of 1986 for under $30.

Construction drawings for the Reinhart grubbing tool and the modified Reinhart tool may be obtained from the Center (request drawing number MEDC-674). The Fyr-Tamer is available from Fyr-Tamer Distributing, 30144 East Woodward Rd., Troutdale, OR 97060; (503) 695–4778.

For land managers faced with replanting steep sites, these new handtools represent a more efficient, cost-effective means for site preparation.

Effect of Various Nutrient Regimes and Ectomycorrhizal Inoculations on Field Survival and Growth of Ponderosa Pine (*Pinus ponderosa* var. *scopulorum* Engelm.) Container Seedlings in Arizona[1]

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Pinus ponderosa var. scopulorum Engelm. container seedlings raised under four nutrient and three mycorrhizal inoculation treatments survived well in the field. Trees inoculated with forest duff survived better than noninoculated seedlings. Generally, seedlings raised under high nitrogen regimes had greater growth. Tree Planters' Notes 37(3):15–19; 1986.

In the Southwest—Arizona, New Mexico, and southwestern Colorado—reestablishment of Rocky Mountain ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) is difficult because precipitation is erratic during critical periods of the year. Nursery stock can be planted successfully when proper procedures are followed (*6,14*). Initial growth of planted seedlings, especially bareroot stock, is very slow (*5*). Seedlings that grow slowly are subject to predation by a host of biotic agents, primarily browsing mammals and insects. Hastening juvenile growth reduces the time trees are susceptible to damaging agents.

Inoculating the roots of many tree species with mycorrhizal fungi has improved survival and growth, especially when the symbionts are ecologically adapted to the site (*9*). In North Dakota, Riffle and Tinus (*13*) found that survival, stem diameter, current height increment, and biomass of ponderosa pine seedlings were increased, after 2 and 3 years, for seedlings inoculated with pine duff, *Rhizopogon roseolus* (Corda) Hollos, or *Suillus granulatus* (L.: Fries) O. Kuntze.

Trees require mycorrhizae to absorb adequate water and nutrients, especially phosphorus (*7,8,10,11*). Greater absorption is likely due to a larger surface area of the roots resulting from the formation of the fungal mantle and from mycelia that emanate from the mantle and permeate the soil. In addition, mycorrhizal roots remain functioning for longer periods of time, whereas uninfected roots are ephemeral (*1*).

Root to shoot ratios have long been considered an important factor in determining initial survival of planted ponderosa pine. Cornett (*3*) has shown that root to shoot ratios (ovendry weight basis) are inversely related to amounts of foliar N, P, and K applied. Thus, if a formula for producing seedlings with short, compact tops and well-developed mycorrhizal root systems could be found, survival and growth in the field should be improved. This field study tested the survival and growth of containerized seedlings raised under four nutrient regimes and inoculated with forest duff or *Pisolithus tinctorius* (Pers.) Coker & Couch (Pt).

Methods

Seedlings. Ponderosa pine container seedlings were raised in the Bureau of Indian Affairs' greenhouse at McNary, AZ, following general guidelines from Tinus and McDonald (*15*).[2] Trees were raised in Tinus Rootrainers (492 cubic centimeters) manufactured by Spencer-Lemaire, Ltd., Canada. Seedling substrate consisted of equal parts of peat moss and vermiculite inoculated with forest duff, Pt, or no inoculum (*3*). Duff was collected from an 85-year-old ponderosa pine stand in central Arizona on a 6- to 8-percent slope with a southwest aspect. Recent litterfall layers were discarded, then humus layers (down to mineral soil) were collected. The material was prepared as inoculum by passing it through a 1.3-centimeter screen. All inocula were mixed with the substrate immediately prior to filling and seeding containers at a rate of 8 percent duff by volume.

Basidiospores of Pt were collected in 1979 from a dry site in Jackson County, OR, at an elevation of approximately 600 meters. The spores were stored dry at a temperature of 2 to 4 °C until used as inoculum. At that time, 100 milligrams of Pt spores was suspended in a 2-liter solution of distilled

[1]The research reported here was conducted at the Rocky Mountain Forest and Range Experiment Station's research work unit at Flagstaff in cooperation with Northern Arizona University.

[2]Seedlings were raised by Cornett as part of a Ph.D. research project at the University of Arizona, Tucson. However, this study was not a part of the dissertation.

water to which 0.75 milliliter of the surfactant Tween 80 was added. The mixture was then returned to cold storage. Spores were applied at a rate equivalent to 0.1 milligram per 0.09 square meter of exposed substrate when the containers were filled. This was done by mixing the appropriate amount of suspension in several liters of water, then pouring it over vermiculite. The treated vermiculite was then mixed well with the rest of the substrate and the containers were filled (3).

Seedlings were watered with Peters soluble fertilizer (15–30–15) applied as a foliar spray three times a week for 6 weeks and two times a week for 5 weeks. Fertilizer treatments were calculated to supply 30, 45, 60, and 75 parts per million (ppm) nitrogen. Peters' Stem (containing S, B, Cu, Fe, Mn, Mo, and Zn) was added in equal amounts to each of the four treatment solutions along with equal amounts of iron chelate (sodium ferric diethylenetriamine pentacetate, 10 percent by weight). Fertilization was begun 4 weeks after seed were sown.

Root to shoot ratios and mycorrhizal infection rates at the end of the greenhouse experiment are listed in table 1. After the greenhouse experiments (3), 240 of the seedlings were planted on the Fort Valley Experimental Forest, approximately 24 kilometers northwest of Flagstaff, AZ.

Site. The study site is on level terrain at an elevation of approximately 2,225 meters. Soils are silt loams derived from basalt parent material. Most of the mature ponderosa pine overstory had been removed in the 1960's. Tree cover now consists of pole-sized ponderosa pine originating in 1919. Ground cover is primarily Arizona fescue (*Festuca arizonica* Vasey) and mountain muhly (*Muhlenbergia montana* (Nutt.) Hitchc.).

In 1976, grass openings were sprayed with a mixture of dalapon (6.63 kilograms active ingredient (ai) per hectare) and atrazine 80-W (5.6 kilograms ai per hectare) before bareroot seedlings were planted. The planting was a failure because of poor quality nursery stock. In 1982, a small opening about 15 meters by 15 meters, still free of live grass, was selected for this study.

The study consists of four randomized blocks, each with 12 rows of five trees. Each row was randomly selected for planting with seedlings raised under one of the regimes (combination of nutrient and inoculation treatment) shown in table 2.

Trees were planted with planting bars at a spacing of 0.9 meter by 0.9 meter at the end of July 1982. There was a space of 0.9 meter between blocks. After planting, mesh plastic seedling protectors were placed around each tree and secured with two wire pins.

Measurements. Seedling survival was recorded periodically in 1982 and 1983 with the following notation: 1 = alive—growing, 2 = alive—not growing, and 3 = dead. Seedling heights were measured in the spring of 1983 before growth began and in the fall after growth ceased.

Table 1—*Root to shoot ratios and extent of mycorrhizal infection for container ponderosa pine seedlings raised in the greenhouse under various nitrogen supplementation regimes and inoculation treatments*[1]

Treatment	Root/shoot ratio (ovendry weight) (g/g)	Mycorrhizal infections (percent short roots infected)
N supplementation		
30 ppm	0.916 a	40 a
45 ppm	.926 a	26 b
60 ppm	.770 a	20 b
75 ppm	.758 b	22 b
Inoculation		
Control (none)	.725 a	14 a
Duff	.741 a	16 a
Pt	.707 a	16 a

[1]Means with the same letter in common are not significantly different (P = 0.05) as determined by analysis of variance. Differences in means determined by Student-Newman-Keuls multiple range test.

Table 2—*Effect of greenhouse N supplementation and inoculation on growth characteristics and survival of ponderosa pine outplanted in Arizona*

Greenhouse treatment[1]	Total height[2] (cm)	Height growth[2] (cm)	Survival[3] (%)
30 ppm N			
Control	15.5 bc	5.8 d	90 a
Duff	16.5 d	5.2 cd	95 a
Pt	12.9 a	3.3 b	95 a
45 ppm N			
Control	14.6 b	4.4 c	90 a
Duff	17.5 de	5.1 cd	100 a
Pt	15.8 cd	3.1 a	80 a
60 ppm N			
Control	19.2 e	6.1 d	85 a
Duff	15.0 b	3.2 ab	100 a
Pt	15.8 bcd	5.7 d	95 a
75 ppm N			
Control	15.4 bcd	6.0 d	85 a
Duff	18.0 e	5.2 cd	95 a
Pt	19.5 e	5.5 cd	90 a
Mean	16.3	4.9	92

[1]Pt = *Pisolithus tinctorius*.
[2]Treatments followed by the same letter are not significantly different (P = 0.10) as determined by analysis of variance (LSD = 0.05).
[3]Treatments with the same letter in common are not significantly different as determined by Chi square.

Table 3—*Field survival rates of ponderosa pine container seedlings averaged by greenhouse treatments*[1]

Treatment[2]	Survival (%)
N supplementation	
30 ppm	93 a
45 ppm	90 a
60 ppm	93 a
75 ppm	90 a
Inoculation	
Control	88 a
Pt	90 ab
Duff	98 b

[1]Treatment values with the same letter in common are not significantly different (P = 0.1) as determined by Chi square.
[2]Pt = *Pisolithus tinctorius*.

Because of interaction between nutrients and inoculation treatments, and heterogeneous variance among the treatment combinations, total height and height growth for the 12 treatment combinations were analyzed by randomized block analysis of variance, followed by heterogeneous variance LSD pairwise multiple comparisons when a significant overall F test of treatment differences was first observed (2). Survival was analyzed with Chi square techniques.

Results and Discussion

In spite of the fact that seedlings were enclosed by protectors, 28 percent of the trees were browsed by elk (*Cervus elaphus*), which knocked the protectors over. Nevertheless, overall survival (92 percent after one and a half growing seasons) was excellent (table 2). Individual treatment means did not differ significantly (table 2); however, results averaged across nutrient levels showed that seedlings inoculated with forest duff survived significantly better than noninoculated trees (table 3).

Even though significant treatment effects were observed for both total height and height growth (P = 0.05), the interaction of nutrient level and inoculation treatment clouds the analysis of individual effects of added nutrients and inoculation. Generally speaking, height growth was greatest under high N regimes (table 2), although noninoculated seedlings exhibit high growth rates for the lowest N level. Seedlings inoculated with Pt exhibited less growth for the two lowest N levels than for the two highest levels. Seedlings inoculated with duff grew equally at all but 60 ppm N. Patterns of total height response were similar except that total height of noninoculated seedlings was high only at 60 ppm N.

Root to shoot ratios of the seedlings used in this study were inversely related to N application

rates but not to mycorrhizal fungi. A similar finding for ponderosa pine inoculated with Pt was reported by Trappe (*16*). However, results from this experiment tend to minimize the importance of root to shoot ratios as a factor in the establishment of ponderosa pine container seedlings in the Southwest. Seedlings raised under the lowest N regime had a root to shoot ratio, before planting, of 0.916 but did not survive better than seedlings raised under the highest regime, which had the lowest root to shoot ratio (0.758). A similar conclusion was reached by Racey et al. (*12*), who found top length, stem diameter, top volume, and root volume to be better indicators of nursery stock quality and potential growth performance than top to root ratios for red pine (*Pinus resinosa*) bareroot seedlings. Tinus and Ronco[3] found little correlation between root to shoot ratios of container seedlings and field survival in Arizona and New Mexico.

Root to shoot ratios and mycorrhizae may be more important in improving survival under conditions more adverse than those in this study. During the first year after these seedlings were planted, more than 635 millimeters of precipitation fell on the study site. Almost 102 millimeters of rain fell in the first month after planting. Normal precipitation for the year in this area is about 559 millimeters.

In the same area, Cornett (*4*) found that significantly more of the ponderosa pine container seedlings inoculated with *Suillus granulatus* survived than did controls during an abnormally dry year.

Although in this experiment there was not a strong effect on survival rates by inoculation treatments, there is an indication that survival is improved by inoculation with forest duff, presumably because of the presence of native mycorrhizal fungi. Growth of seedlings was not improved by inoculation treatments.

[3]Unpublished data on file, Rocky Mountain Forest and Range Experiment Station, Flagstaff, AZ 86001.

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Raspberry (*Rubus idaeus* L.) Competition Effects on Balsam Fir (*Abies balsamea* (L.) Mill.) Seedlings in Northern Maine[1]

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The effects of competition from raspberries on the growth and nutrient quality of the foliage of balsam fir seedlings were evaluated. Seedlings overtopped by raspberries were smaller than open-grown seedlings. Root collar diameters averaged 5.5 and 8.2 millimeters in the overtopped and open-grown seedlings, respectively. Foliar analysis revealed higher P (0.18 versus 0.16 percent) and lower K (0.59 versus 0.80 percent) concentrations in the open-grown seedlings than in the overtopped seedlings. Nutrient proportions in both groups of seedlings deviated from proposed optimum levels. The foliar analyses indicated K deficiencies in the open-grown seedlings and possible luxury consumption of Ca in both groups. Tree Planters' Notes 37(2):20–23; 1986.

Clearcutting is common in the spruce–fir stands of northern Maine. A dense cover of raspberries frequently becomes established following clearcutting, and can suppress small spruce and fir seedlings (2, 6). This may increase the time required for these stands to reach merchantable size.

Foliar analysis is often used to evaluate the nutritional status of forest trees (22). Critical levels have been established for the essential elements in many species (15). However, examination of individual nutrient concentrations alone is inadequate to characterize the nutrient status of a tree. Maximum growth occurs only when the proper ratio among nutrients occurs in combination with optimum concentrations (20). Work with black spruce (*Picea Mariana* (Mill.) B.S.P.), white spruce (*P. glauca* (Moench) Voss), and Scotch pine (*Pinus sylvestris* L.) has led to the proposal of an optimum nutrient proportion (expressed as a weight relation to nitrogen) of: N = 100, P = 13, K = 65, Ca = 6, Mg = 8.5, S = 9, and Fe = 0.7 (8–10, 22, 23).

In this study, foliar analysis and growth data were used to investigate the impacts of raspberry competition on the growth and elemental composition of balsam fir seedlings.

Materials and Methods

This study was conducted in township T5R12, located between Chesuncook Lake and Baxter State Park at 46° N. and 69° W. in northern Maine. The climate in this region is continental. Total annual precipitation averages 92 centimeters, with snow falling between November and March (4). Soils of the Telos (coarse-loamy, mixed, frigid Aquic Haplorthod) and Monarda (coarse-loamy, mixed, nonacid, frigid Aeric Haplaquept) series were characteristic of the study area.

The uncut stands in the area were approximately 60 years old and originated following the spruce budworm outbreak of 1913–19 (19). Red spruce (*Picea rubens* Sarg.) and balsam fir were the principle components. Scattered eastern white pine (*Pinus strobus* L.), paper birch (*Betula papyrifera* Marsh.), and black spruce also were found. The stands were fully stocked, with the overstory basal area averaging about 28 square meters per hectare. Abundant advanced spruce and fir regeneration existed in the understory.

Five adjacent clearcut strips were located in 1979. The strips had been harvested with mechanical feller-bunchers during the winter of 1974–75. The strips were approximately 30 meters wide, oriented northeast–southwest, and were separated by strips of uncut timber 45 to 60 meters wide.

Two groups of 10 balsam fir seedlings were selected in each clearcut strip in October 1979. Half the seedlings were overtopped by raspberries, whereas the remainder were free to grow.

The total height and the root collar diameter of each seedling were measured. Seedlings were then severed at the root collar, and seedling age was determined by

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counting the annual rings. The current year's foliage was collected from each seedling and put together with the foliage from all other seedlings within each group.

These composite foliage samples were dried at 70 °C and ground in a Wiley mill to pass a 0.84-millimeter screen. Nitrogen was determined by a micro-Kjeldahl procedure (*14*). Phosphorus was determined by the vanadomolybdate-HNO_3 procedure following dry ashing at 500 °C (*5*). Ten milliliters of 0.33 *M* magnesium acetate was added to the ground sample and evaporated prior to dry ashing to prevent volatilization of P. Cations were determined following dry ashing at 550 °C. Calcium and magnesium were determined by atomic absorption, and potassium was determined by flame emission spectrophotometry. Sulfur was determined colorimetrically following a nitric–perchloric acid digest (*5*).

The student's *t*-test was used to determine differences in age, height, root collar diameter, and foliar nutrient concentrations between open-grown and overtopped seedlings (*11*).

Table 1—*Age, height, and root collar diameter and nutrient concentrations in the foliage of balsam fir seedlings growing in clearcuts in northern Maine*[1]

Seedling condition	Age (yr)	Height (cm)	Root collar diam. (mm)	Nutrient conc. (%)					
				N	P	K	Ca	Mg	S
Overtopped	6.2 a	36.2 a	5.5 a	1.30 a	0.16 a	0.80 a	0.51 a	0.11 a	0.12 a
Open-grown	6.4 a	47.9 a	8.2 b	1.27 a	0.18 b	0.59 b	0.57 a	0.10 a	0.11 a

[1]Values in a column with the same letter are not significantly different (Alpha = 0.05).

Results and Discussion

The average age of both the overtopped and the open-grown seedlings was 6 years (table 1). Thus, the regeneration present in these 5-year-old clearcuts originated from seedlings that existed in the understory at the time of harvest. Such advanced regeneration is a common feature in spruce–fir stands in eastern North America (*1*), and is the principle source of regeneration following clearcut harvesting (*3*).

The open-grown seedlings in this study were larger than those overtopped by raspberries (table 1). Competition from raspberries appears to have retarded the growth of these seedlings, particularly with respect to diameter. Similar results have been reported by Holt and coworkers (*7*).

Nutrient concentrations in the foliage of the sampled seedlings are presented in table 1. Significant differences were found in P and K concentrations between overtopped and open-grown seedlings. Nutrient proportions in the two groups of seedlings and comparisons with proposed optimum values are presented in table 2. The nutrient ratios in both groups of seedlings deviated from the proposed optimum proportions.

Although statistically significant, differences in P concentrations were relatively small. Lowry and Avard (*12*) found no difference in P concentrations among crown classes in black spruce. However, van den Driessche (*21*) reported higher P concentrations in suppressed trees. It is doubtful that the differences found in the present study are biologically significant. Phosphorus concentrations were above critical levels (*15*), and the ratio of P to N is very close to the optimum value in both groups of seedlings (table 2).

Table 2—*Nutrient proportions in the foliage of balsam fir seedlings growing in clearcuts in northern Maine compared with optimum values (N set at 100)*

Nutrient	Overtopped	Open-grown	Optimum value[1]
N	100	100	100
P	12.3	14.5	13
K	61.5	46.5	65
Ca	39.2	42.3	6
Mg	8.3	7.7	8.5
S	9.1	8.6	9

[1]van den Driessche (1976).

Large and statistically significant differences in foliar K concentrations existed between the overtopped and open-grown seedlings, with higher K concentrations in the overtopped seedlings. Similar results have been reported with black spruce (*12*) and red pine (*Pinus resinosa* Ait.) (*13*). In addition, the K to N ratio in the open-grown seedlings was the only nutrient proportion that deviated below the optimum by more than 10 percent, thus indicating a severe K deficiency. Growth dilution in the open-grown seedlings may be responsible for these differences.

An extremely high Ca to N ratio was found in both the open-grown and the overtopped seedlings. The values were between 6 and 7 times greater than the suggested optimum value. When data from other studies of balsam fir are used to construct nutrient proportions, high values for the Ca to N ratio are also obtained (*16, 17, 24*).

Because of an imbalance in the age structure of the spruce–fir forests in the Northeast, attributed to the cyclic nature of outbreaks of the spruce budworm, *Choristoneura fumiferana* (Clemens), a softwood timber shortage has been predicted for this region (*18*). Regeneration delays induced by raspberry competition would exacerbate this shortage. The research presented in this paper has shown that competition from raspberry plants reduces growth and affects tree nutrition of balsam fir seedlings, which could contribute to the timber shortfall problem. Additional work is needed in this area. In particular, the optimum nutrient proportions in balsam fir foliage need to be identified.

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Performance of Fall- and Spring-Planted Bareroot and Container-Grown Red Pine (*Pinus resinosa* Ait.)

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Red pine (Pinus resinosa *Ait.) styro-plug, 2–0, 3–0, and 2–2 seedlings were planted in the fall and spring. After four field seasons for the spring-planted seedlings and three for the fall-planted seedlings, survival and height growth of the container seedlings was similar to that of the 2–0 and 3–0 seedlings. The 2–2 transplant stock generally outperformed all the other stock classes. Planting season had no significant effect on survival of container stock. Average annual height growth was better on spring-planted trees than on fall-planted trees, irrespective of stock class.* Tree Planters' Notes 37(2):24–26; 1986.

Recent symposia on artificial regeneration and intensive management in the Lake States, plus projected needs for softwoods, have stimulated interest in intensive management of red pine (*Pinus resinosa* Ait.) plantations (2). Research needs include documentation of the survival and growth of bareroot and container seedlings on various sites. There is also renewed interest in the prospect of fall planting to widen the existing reforestation window. This paper compares the performance of bareroot and container red pine seedlings planted in the spring and fall in east central Minnesota.

Materials and Methods

Three types of nursery-grown bareroot stock (2–2 transplants and 3–0 and 2–0 seedlings) and styro-plug container-grown seedlings were planted in spring and fall 1980. These results include four growing seasons for spring-planted trees and three growing seasons for fall-planted trees.

The prior cover type on the study site consisted of quaking aspen (*Populus tremuloides* Michx.), paper birch (*Betula papyrifera* Marsh.), and red maple (*Acer rubrum* L.). After the harvest of commercial trees in 1979 the area was scarified by root raking. The soil is a moderately well-drained Ahmeek-Ohmega sandy loam underlain by a fine, sandy loam fragipan.

The styro-plug containers (35 cubic centimeters rooting volume) were seeded in November 1979, grown in a greenhouse, and placed outside in May 1980 until planted. Both spring- and fall-planted containers were from the same greenhouse crop. Spring-planted bareroot trees were lifted from the nursery and stored for about 1 week under refrigeration before being planted. Spring planting of bareroot stock was on May 14 and container stock on June 3, 1980. Fall-planted bareroot stock was planted on the same day it was lifted from the nursery. All fall planting was done on September 23, 1980. Container stock was planted using a Potti-putki planting tube. The bareroot stock was planted using a standard planting bar.

Measurements taken of sample seedlings at time of planting indicated that the quality of all stock was within acceptable standards except the high shoot to root ratio of fall-planted 3–0 stock (table 1).

A randomized block design was used with four replications of each treatment combination (stock × season). Each treatment combination had 50 trees per replication for a total of 1600 trees in the entire study.

Evidence of browse damage by snowshoe hares (*Lepus americanus* Erxleben) was noted in October 1980. To reduce further browse damage, mesh plastic netting was placed around each seedling.

Primary vegetative competition on the site was quaking aspen and balsam poplar (*Populus balsamifera* L.), various willow species (*Salix* spp.), grasses, and sedge. The trees were chemically released in August 1982.

Survival and height measurements are summarized in table 1. Height growth was calculated as the average per growing season.

Results

Planting season comparisons. Spring-planted bareroot stock had significantly greater survival and

[1]The authors thank the Potlatch Corporation, Minnesota Wood Products Division, for its help in conducting this study. This article is University of Minnesota Agricultural Experiment Station Science Journal Series Paper No. 1989.

height growth than stock planted in the fall. Season of planting had no significant effect on survival of container stock but, similar to bareroot stock, mean annual height growth was less on fall-planted trees (table 2). Heights at the end of the measurement period are also shown in table 2 but keep in mind that the spring-planted stock had an additional growing season in the field.

Planting stock comparisons. Survival of the container and bareroot stock was similar, with two exceptions. Survival of spring-planted 2–2 stock was significantly higher than the 3–0 and container stock. Survival of fall-planted 3–0 stock was significantly lower than the other types of stock (table 2).

Height differences were not consistent between spring- and fall-planted seedlings. Average height of spring-planted container stock was significantly shorter than that of the spring-planted bareroot stock. But, the height of fall-planted container stock did not differ significantly from that of the 2–0 and 3–0 stock. The 2–2 stock was significantly taller than all other stock types at the end of the measurement period, as it was at the time of planting; however, it did not necessarily grow faster than the 2–0 and 3–0 stock (table 2). The mean annual height growths of spring-planted container, 2–0 and 3–0 stock did not differ statistically. Average annual height growth of fall-planted container and 3–0 stock was substantially less than either the 2–0 or 2–2 stock.

Table 1—*Physical characteristics of stock at time of planting (N = 20)*[1]

Stock type	Stem diam. (mm)		Shoot ht. (cm)		S/R ratio[2]	
	Spring	Fall	Spring	Fall	Spring	Fall
Container	1.6 d	2.1 d	9.5 c	9.7 b	2.3	1.1
2–0	3.0 c	3.1 c	7.5 d	6.1 c	3.6	3.1
3–0	3.7 b	4.0 b	16.7 b	23.2 a	4.1	6.7
2–2	5.5 a	7.1 a	20.1 a	24.7 a	4.3	3.9

[1]Means within a column and planting season with the same letter are not significantly different (P = 0.05).
[2]Shoot to root ratio based on ovendry weight.

Table 2—*Comparisons of mean survival, mean height, and mean annual height growth of spring- and fall-planted red pine stock types*[1]

Planting season	Container	2–0	3–0	2–2	Average
Mean survival (%)					
Spring	82 ay	91 axy	82 ay	97 ax	88
Fall	73 ax	74 bx	51 by	85 bx	71
Mean height (cm)					
Spring	59 az	76 ay	72 ay	102 ax	81
Fall	33 by	36 by	34 by	59 bx	43
Annual height growth (cm)					
Spring	12 ay	17 axy	17 axy	22 ax	17
Fall	4 by	10 bx	6 by	12 bx	8

[1]Bareroot seedlings were planted in the spring on May 14, 1980; containerized seedlings on June 3, 1980. Seedlings were planted in the fall on September 23, 1980. Means within a column (a, b, c) or across a row (x, y, z) followed by different letters differ significantly (P = 0.05).

Height comparisons between the various stock types were affected by both the hare browsing and the subsequent use of the plastic mesh, which restricted height growth in some instances. In order to remove the effects of those influences, damaged trees were not included in the height summary and analysis.

Conclusions

Spring planting resulted in superior survival and growth rates for the 2–2, 3–0, and 2–0 stock in comparison to the fall-planted bareroot stock. Results similar to these have been documented in other studies of red pine regeneration (*3, 4, 6*). Seedlings grown in styro-plug containers had similar survival rates irrespective of planting season, but spring-planted containers

grew at a faster rate than those planted in the fall.

Survival and height growth of the container seedlings was comparable to those of the 3–0 seedling stock. Survival of container stock was similar to that of 2–0 seedlings, but fall-planted 2–0 stock grew at a substantially faster rate. As a result of acceptable field performance, similar to that found in this study and others, use of containerized seedlings as a supplement to bareroot stock has been increasing in the Lake States (*1*). Survival and height growth of the 2–2 transplant stock was as good as or better than that of the other stock types. The superior performance of red pine transplants over seedlings is well documented in the literature (4–6).

It must be noted that this study encompasses a single planting season and set of environmental conditions. Comparisons such as these must be repeated through time under various conditions. The results, however, do provide supportive data and aid in evaluation of stock type and planting season.

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A Seedbed Comparison of Two Seed Sources of White Spruce (*Picea glauca* (Moench.) Voss) at the Maine State Forest Nursery

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*White spruce seedlings (*Picea glauca *(Moench.) Voss) grown from superior seed, collected in the Ottawa Valley, had significantly greater shoot heights and root lengths than seedlings grown from commercial seed from Michigan. Stem diameters and shoot to root ratios were not significantly different.* Tree Planters' Notes 37(2):27–28; 1986

White spruce (*Picea glauca* (Moench.) Voss) at the Maine State Forest Nursery, Greenbush, is grown as 3–0 stock, with 8 inches of shoot height designated as the minimum size for shipping. If an 8-inch plantable seedling could be produced in 2 years instead of 3, production costs would decrease considerably and fields could be put into a cover crop rotation more easily. This study was conducted to determine if the use of an improved source of seed could reduce production time for white spruce seedlings.

Materials and Methods

Ottawa Valley white spruce seed has been determined through a series of provenance tests in Canada and the United States to be a consistently superior performer under most circumstances. Teich, Morgenstern, and Skeates (5) compared Canadian sources of seed on planting sites in Ontario and found a "consistency in the origin of productive provenances." This area was the Cobourg–Beachburg corridor in the lower Ottawa River valley. In a more widely ranging Canadian study, Teich (4) determined again that the lower Ottawa Valley sources were generally about 20 percent taller than plantation averages. Nienstaedt (2) studied seed sources from a wider range and found that the Ontario sources were among the top ten best sources in each of the 14 outplantings used.

In the spring of 1980, 500 grams of Ottawa Valley white spruce seed (collected in Algonquin Provincial Park) were seeded by hand in a production bed at the Maine State Forest Nursery, Greenbush. The bed was given the same cultural treatments as the regular production beds, which had been mechanically seeded with a commercially collected seedlot from Michigan. Density in the beds was approximately the same, 34 trees per square foot. After three growing seasons, the trees were lifted, and 20 trees from each source were selected randomly and measured for shoot height, root length, and stem caliper at the root collar. Shoot to root ratios were calculated from these measurements.

Results and Discussion

By use of an unpaired *t*-test, it was determined that both shoot height and root length were significantly different for the two seed sources, whereas root collar diameter was not (table 1). Due to the non-normality of the distribution of the shoot to root ratio generated here, the Mann-Whitney nonparametric test was used to compare shoot to root ratios for the two sources. This comparison also showed no significant difference. This was not unexpected, as production of a well-balanced seedling should be evident at any stage of development.

Seedlings from the Ottawa Valley source were significantly taller than those from the Michigan source by 20.2 percent (2.16 inches), according to the results obtained from the *t*-test. They were taller than the 8-inch minimum height by 60.5 percent (4.84 inches). The smallest individual from the Ottawa Valley

Table 1—*Growth characteristics of white spruce seed from two sources (N = 20)*

Source	Shoot height (in)	Root length (in)	Root collar diameter (in)
Ottawa Valley	12.84**	14.80*	0.23 NS
Michigan	10.68**	11.30*	0.21 NS

*Significantly different at the 5-percent level (unpaired *t*-test).
**Significantly different at the 1-percent level (unpaired *t*-test).
NS = Not significantly different (unpaired *t*-test).

source was 1.5 inches taller than the minimum, whereas the smallest individual from the Michigan source was 0.25 inches shorter than the minimum.

Mullin and Bowdery (*1*) suggest that a sturdier, more plantable seedling may be produced by a reduction in seedbed density, perhaps a drastic reduction, to 10 seedlings per square foot. Reese and Sadreika (*3*) describe acceptable bareroot planting stock of 3–0 white spruce as being between 22 and 28 centimeters (8.7 to 11.0 inches) in height and acceptable 2–0 planting stock as being between 10 and 16 centimeters (3.9 to 6.3 inches) in height.

Results indicate that with a reduction in seedbed density to less than 20 trees per square foot and the use of superior white spruce seed, such as the Ottawa Valley source, the Maine State Forest Nursery may be able to produce a plantable white spruce seedling in 2 years, meeting and probably exceeding the Ontario standard for 2–0 stock and meeting the present Maine standard for 3–0 stock. A reduction in seedbed density might also reduce the number of cull trees, further decreasing production costs. These possibilities need further investigation.

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Walnuts and White Pine Can Be Grown Together Successfully

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*Small plantings of mixed eastern white pine (*Pinus strobus *L.) and black walnut (*Juglans nigra *L.) planted on the same site appear to be healthy after 15 to 18 years. These plantations are producing trees of desirable silvicultural form.*
Tree Planters' Notes 37(2):29–31; 1986.

Many cultural problems await the novice landowner during the early years of walnut plantation establishment. Insect damage to leaders, epicormic sprouting, and girdling by meadow mice are a few examples. These problems may require annual corrective pruning or other cultural practices. Many landowners do not have the time, money, or patience for all this management.

The challenge presented to the forester is formidable. How do you establish a walnut plantation that will virtually take care of itself for 10 to 15 years? Usually, by then stem crowding is so apparent that even the most reluctant landowner will concede that an improvement cutting is in order. One answer to this challenge in southwest Wisconsin is the interplanting of white pine and walnut. Several plantations of this mixture were established 15 to 20 years ago, and the effectiveness of the combination is encouraging.

There has been concern about the dangers of growing white pine and walnut together in plantations. Walnut trees produce the chemical juglone (5-hydroxy-1,4-naphthoquinone), which inhibits the growth of white pine. This growth inhibition seems to occur where white pine is planted beneath an established walnut overstory with the objective of bringing the white pine through to rotation age. But evidence from even-aged (15 to 20 years) plantations of mixed white pine and walnut appears to remove this concern (figures 1 and 2).

The planting design starts with the first row being planted to pure 3–0 white pine on a 6–foot spacing. The second row is planted to white pine alternated with 1–0 walnut on the same spacing. Rows are spaced 6 feet apart. These two basic rows are replicated over and over. When a plantation is completed, each walnut is surrounded by white pine. Approximately 300 walnut and 900 white pine are needed to cover an acre.

It is very important that the plantation be kept from grass competition during the first 2 years. This is best accomplished by applying a band of simazine to each row of

Figure 1—*Fifteen-year-old mixed plantation of walnut and white pine in northwest Grant County, southwestern Wisconsin. Very little improvement has been accomplished.*

Figure 2—*Nineteen-year-old mixed plantation of walnut and white pine in northeast Rock County, southern Wisconsin. Three improvement cuts were made (1977, 1981, 1984), and the walnut crop trees were pruned to 12 feet.*

the planting. Consult your local forester for the amount of chemical to apply. The rate of application will depend on the soil type and amount of grass competition or weeds present.

This white pine–walnut plantation prescription can be planted in many areas of southern Wisconsin, and on a wide range of sites. However, it works best on a well-drained, silt loam with a soil acidity between 6.0 and 7.0. Areas to avoid are river bottoms and valley floors where prolonged periods of high humidity in midsummer are common. These conditions may produce blister rust infection in the white pine as well as bacterial and fungal infections in the walnut.

In the early years of this prescription (ages 7 to 9) a modest thinning of white pine Christmas trees can be anticipated to help defray the cost of stand establishment. From ages 10 to 15, a genetic thinning is necessary. At this time, trees with better genetic traits will express their dominance; and additional growing space will favor future development of these trees. By age 15, the stocking of the stand should be reduced from 1,200 per acre to 700. Pruning should be done to half the height of the tree, whether walnut or white pine (figures 1 and 2).

The unusual aspect of mixing a conifer and a fine hardwood is that it gives landowners options that are not possible with pure plantings. Landowners may want to favor a walnut by cutting adjacent white pine. They can favor a fast-growing white pine by cutting deformed or poor-growing walnuts. It is entirely possible to bring white pine and walnut growing on the same site to final sawlog rotation.

A 60-year-old white pine plantation in Wyalusing State Park is living testimony to just how well walnut and white pine can grow together (figure 3). This 1923 planting of white pine now has dominants over 115 feet in height and a basal area of 220 square feet. As this planting developed, many walnut volunteers began to appear throughout the plantation. Today these walnut trees are saw-timber size, with 30 to 40 feet of clear

trunk. There is no apparent adverse effect from the walnut trees growing in close proximity to the white pine for 60 years.

The adaptations are limitless on the species mix of this prescription. For instance, for landowners who want to grow a desirable fuelwood species along with their walnut and white pine, it is possible to add green ash to the design. In this case, the design can be altered by substituting a green ash for every other walnut.

With high land prices and property taxes, foresters must be imaginative and innovative in their planting prescriptions. Every effort must be made to maximize returns for the landowner if we are to keep interest alive in forest management. Mixing of conifers and hardwoods is another option that foresters now have in assisting landowners to get the maximum return from a forestry investment.

Figure 3—*Sixty-year-old plantation of white pine with volunteer walnut trees in Wyalusing State Park, southwest Wisconsin.*

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Cover: Hand planting crew on the Desoto National Forest in Mississippi, January 1986.

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Italic numbers in parentheses in the text refer to numbered literature citations at the end of each article.

Tree Seed Handling and Management—Part I

Earl W. Belcher

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Participants in recent nurseryman's conferences around the country have asked for a reference series to help them with their seed handling. The 48 topics they proposed will be covered in a series of articles here in Tree Planters' Notes. Tree Planters' Notes 37:3–7; 1986.

1. Seed moisture—How dry is too dry?

Under most conditions of seed extraction in the South, the moisture of the seed upon arrival at the container is between 9 and 12 percent. However, during humid weather, such as a week of rain, the seed may have a moisture content between 12 and 16 percent when removed from the kiln.

Research has shown that the moisture threshold for the seed of most tree species is around 10 to 12 percent, except for the recalcitrant seed, such as acorns. Seed of the family Fagaceae require moisture contents above 20 percent to maintain viability. These species are considered short lived and usually are stored for no more than one season.

Conifer seed, on the other hand, may be stored for long periods of time, with few exceptions, if the moisture content is below the threshold value of 10 to 12 percent. Seed of most conifers can be stored satisfactorily at 34 °F with an 8 to 10 percent moisture content when the seeds are sealed in moisture-proof containers. This may present a problem, because there is no margin of safety, and seed temperatures could increase rapidly if compressors stop working in the middle of the summer.

Chemical changes that begin at temperatures above 40 °F usually lead to germination or deterioration. Therefore, most nursery managers store their seed at 20 to 25 °F. This range provides a margin of safety for the seed. The typical insulated storage unit will hold seed temperatures below 40 °F for 48 to 72 hours during a power loss. This period is sufficient for emergency repairs. At this temperature range, the moisture content should be held between 6 and 8 percent. Moisture contents close to 10 percent will tend to increase above a safe level because condensation will form on the seed when the lid is removed for repeated sampling. Higher moisture contents also permit chemical changes to progress, even though slowly, at freezing temperatures, resulting in green embryos within the seed.

Some nursery managers store seed in a commercial freezer. These freezers, designed for preservation of food, maintain a temperature of 0 °F. Under these conditions the moisture content of the seed should be reduced to 4 to 6 percent because moisture may crystallize within the cell at or below this temperature. If there is too much moisture, the cell walls will be damaged, thus leading to deterioration.

The drier the conifer seed, the longer it will store. Samples of red pine (*Pinus resinosa* Ait.) and loblolly pine (*P. taeda* L.) were stored at a moisture content of 1 to 2 percent for 5 years, with annual testing. Viability was consistently above 95 percent. Low moisture levels may be detrimental at high temperatures because the cells are unable to repair damage without sufficient moisture for the necessary chemical reactions. However, seeds held at the same low moisture appear to be superior to seeds held at a higher moisture content for long-term storage. How low the moisture is is not as important as how the low moisture content was reached. Super-low moisture contents (below 5 percent) must be reached slowly with dry air but without excessive heat. High heat may denature enzymes and kill cells. Relative humidities of 20 to 35 percent will produce very low moisture contents in about 10 days under natural conditions (without artificial heat).

If the seed are dried too fast, the moisture is removed from the seed surface faster than it can be moved to the surface from internal cells. This problem creates a differential pressure between cell layers, which I call a "vapor lock." This vapor lock prevents the seed from germinating until the cell pressure is equalized. This phenomenon can be seen by using microwave

drying in a pressure chamber. Seed dried this fast appear to be extremely dormant. They appear to store well but must be hydrated before being stratified. This step is accomplished by placing the seed on a moist surface or in a high-humidity atmosphere for 24 hours.

In summary, the nearer the moisture content of most conifers is to 4 percent, the better for extended storage. Seed stored for 5 years or less may not benefit from the added cost of superdrying the seed. A moisture content of about 9 percent is satisfactory if the seed are frozen. Storage for 1 year or less is possible at a 10-percent moisture content, providing the temperature remains below 40 °F and the moisture content does not increase further.

2. Seed sizing—How much is too much?

The objective of seed sizing is to obtain more uniform sowing and thereby achieve more uniform seedbed densities. Except for Douglas-fir (*Pseudotsuga menziesii*), seed sizing effects have not been found to carry beyond the nursery. Also, in contrast to many articles written on the possible elimination of clones by sizing, there is no possible way to eliminate clones without throwing some of the seed away. At the present value of seed, no one would want to throw away seed, no matter how small or large. However, two problems have led some seed managers to discard seed: the seed were too small to handle or the lot contained too much trash.

Before sizing seed, remove all trash and, if gravity separation is to be used, employ screen sizing first. Gravity can only separate one characteristic at a time. Seed cannot be separated for physical size and density at the same time. Recent studies have shown that physical sizing (screens) account for 90 percent of the benefit in uniform densities. Therefore, serious evaluations should be made before gravity sizing is considered.

The more sizes obtained, the greater the record-keeping and handling. Increasing the number of the sublots also increases other problems of management. As an example, an 800-pound seedlot of pine seed may be sized into three sizes or into five sizes as indicated below.

Seed sizes (screen holes)	Sublot size (lb)	
	Trial A	Trial B
14		42
16	173	131
18	463	463
22	164	158
24		6

Observe that in separating into five sizes, two sublots were obtained with less than 50 pounds each. The minimum lot size should be that required to fill the planter being used. If the planter required 30 pounds, the 6-pound sublot would be mixed with the next size. We must remember that we are striving for more uniform density, not increased record keeping.

Secondly, the question is raised, "How different are these sizes?" The answer is found by computing the number of seed per pound. An example of the seed per pound on the lots sized above is given in the following table:

	Trial A		Trial B	
Seed sizes	Seed/lb	diff.	Seed/lb	diff.
14			19300	
		—		400
16	19000		18900	
		400		300
18	18600		18600	
		2400		2300
22	16200		16300	
				1800
24			14500	

The question arises, "How much difference is required before the planter makes a difference in seed per foot being planted?" Obviously, the more precise the planter, the smaller the difference that will result in a change in density per square foot of bed. Also, the smaller the seed the greater the difference required between sizes to create a difference on the seedbed.

Data from two planting machines showed that less precise machines like the Oliver planter required differences in seed size of more than 2,500 seed per pound before seedlings per square foot changed. The more precise Love planter provided differences in density with differences in seeds per pound of 1,000 seed.

In the examples above, the three sizes will provide only two different densities when sown because none of the planters used would discern differences in size of 400 seed per pound. Therefore, lot A (for practical reasons) has only two sizes as obtained by the 18- and 22-screen sizes. The 16-size sublot can be recombined with the 18. On lot B, there appear to be three sizes, except that the quantity of sublot from screen 24 was only 6 pounds, whereas size 22 was 158 pounds. Although there is a real difference in seeds per pound, there may be too few seeds to keep separate. If combined with the sublot from screen 22, the planter will discharge one seed of sublot 24 for every 30 seeds of sublot 22. Such large ratios will overshadow any differences that might be seen by seed per pound alone. Thus, lot B also consists of only two sublots.

In summary, from the standpoint of results in uniform density for the cost involved, no benefit is derived by keeping sized sublots separate if they are like the examples just cited. No benefit is obtained with any sublots that weigh less than 30 pounds, and that differ by less than 1,000 seeds per pound between sublots. These guidelines assume that reasonably precise seeders are being used. The less precise the seeder, the greater the minimum lot size should be, and the greater must be the seed per pound differences between sublots to realize differences in seedbed density.

3. Vigor, the elusive measurement

Vigor, according to Webster, means strength. The ability of a seed to produce a seedling under stress may be classified as vigor. This term differs from germination, which means the actual production of seedlings. Viability is the potential of seed to produce seedlings but does not provide a relationship to the effect of environmental stress on that potential production.

Germination tests are made under optimum and reproducible conditions so that each test relates to the last test. Germination is not determined under specific field conditions because those conditions may change by planting time. Conversion of germination test results to field expectations is accomplished with a "survival" factor. This factor is based on actual field data collected over time. The factor usually falls between 65 and 80 percent in the South.

"Survival percent" is our attempt to quantify vigor. This term expresses the effect of environmental stress on the potential production of a seedling. According to the International Seed Testing Associa-

tion, "Vigor cannot be quantified because it is a concept. . . ." This statement is not totally true. Vigor is more than a concept, but few analysts know what they are trying to measure. If you had three lots of seed (A, B, and C) you might want to know which lot will give you the most seedlings.

In humans, we can perhaps understand vigor through the following example. A jogger and a nonjogger start out to walk up a steep hill. Part way up, the nonjogger has to sit down and rest because of exhaustion, while the jogger dances around, eager to go again. It is the effective energy of the jogger that relates to high vigor. There is energy to work against stress and to keep going. The exhausted nonjogger displays low vigor. If stress continues, the nonjogger may not complete the intended objective because of insufficient energy. The capacity for endurance can be increased through exercise and practice in humans, but for seed, germination is a single opportunity.

Seeds in a lot seldom all die at once. Rather, they age and die individually. Each lot or sample of filled seed consists of three components: dead, weak, and vigorous seed. A germination test identifies the percentage of dead seed, but does not identify which of the apparently vigorous seed are really weak, because even the weak seed germinate under optimum conditions. Data from studies and field plantings have shown that the percentage of weak seed in the total seedlot can be calculated by multiplying the percentage of germinating seed in the test by the percentage of dead seed. For example, a seedlot germinating 70 percent has 30 percent dead seed; therefore, 30 percent of the sound seed are weak. This calculation means that 21 percent (30 × 70 percent) of the seedlot is composed of weak seed. Seed in this 21-percent portion possess a broad array of weakness. The weakest seed of this portion will die under even low stress, and more will die as the stress increases. At maximum stress they will all die. At this point, even vigorous seed may be affected by extreme conditions. What we attempt to measure is the portion of the weak category that will die under various stresses such as drought, cold, or fungal infection. The problem is to predict what environmental stresses may occur. Because these potential stresses are not known, we only rate the vigor of a seedlot according to other lots or according to a series of specific stresses such as an array of temperatures.

In summary, many of the so-called vigor tests do not relate to vigor at all but rather are viability estimates. The only true vigor tests are those that either relate lots with similar germination rates to a given stress, or a single seedlot to varying environmental stresses. A measure of vigor to temperature may be quite different from a measure for drought. This complication makes vigor measurements difficult! Thus, there is no direct measurement of vigor; only a relative measure in the comparison of two or more lots or two or more stresses.

4. Impact damage, the quiet death of a seedlot

Tree seed are at their maximum potential viability at maturation. This potential may be reduced by environmental impacts, human intervention, or natural aging.

Viability of seed is affected by many factors. Mechanical damage allows organisms and moisture to readily enter the seed and initiate deterioration. High temperatures may denature enzymes or desiccate tissue, which also leads to a catastrophic death. Elevated moisture contents promote chemical change and support cell division at room temperatures. At cooler temperatures, the heat of respiration usually leads to deterioration. And then there is the natural aging process.

Cell division cannot take place during dry storage. Metabolism is also reduced to a very low level. However, a large amount of cell membrane damage does occur, which leads to a slow death known as aging. The rate of death due to aging is related to seed moisture content and existing temperatures.

Aging is increased by increases in both temperature and seed moisture content.

The least observed--and yet one very common—cause of seed loss is the subtle "quiet death" from impact damage. This kind of damage is similar to the bruise you might experience if you were to trip and fall on a concrete floor. A slight redness immediately gives way to a darkening the next day and eventually a black and blue spot. The bruise on the seed is usually insignificant at the time of processing and will not affect germination at that time. After a short storage period, the extent of damage is observed in abnormal germination. The injury leads to reduced germination, which gets worse with time. The loss in germination is caused by deterioration of individual seeds and can be monitored through germination tests.

Impact damage is very difficult to identify in a single test, but quite easy to recognize in a series of tests over time. The first indication is an increased number of seedlings with endosperm collars.

Impact damage occurs when the seed bounces off elevators and machine parts. Each contact with a solid surface bruises a few cells or a small amount of tissue. Damage is only evident when the bruises are either numerous enough or large enough to affect germination. Impact damage increases as the number of contacts rises and with seeds that have a reduced moisture content. That is, a dry seed is more subject to impact damage than is a moist seed. Increased moisture provides some cushion against the impact.

In summary, seed viability can be improved by not only correction of the visible damages, but also by reducing the "slam-bang" of fast operations. Making seed processing more of a fluid operation, that is, a smooth flow, can increase seed germination by eliminating impact damage.

Collection Procedures Affect Germination of Northern Red Oak (*Quercus rubra* L.) Acorns

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*Specifics of acorn collection procedures affect germination in northern red oak (*Quercus rubra *L.) and can be important in obtaining a sufficient acorn supply. Tree-collected acorns had better germination than ground-collected acorns. Acorns that sank during water flotation had a high germination percent regardless of whether they were tree or ground collected. Tree-collected floaters did not significantly lower germination than either tree- or ground-collected sinkers. Ground-collected floaters had the lowest germination. The original position of acorns in the tree crown had no significant effect on germination. Water flotation is recommended for all acorn collections.* Tree Planters' Notes 37(3):8–12; 1986.

Acorn crops differ greatly from tree to tree, from location to location, and from year to year (*8*). Add to this the problems of long-term storage for red oak acorns (*10*), and the specifics of acorn collection become important in obtaining an acorn supply sufficient for forestry purposes.

We studied the viability of acorns collected from the ground and from the tree in one study and from several positions within a tree in another. We also tested water flotation as a method of determining viability. Our findings should be helpful to foresters and nurserymen who wish to propagate oak, particularly in poor seed years.

Although mature acorns are most commonly collected from the ground after they fall, they can be collected after manual or mechanical shaking or they can be picked off the tree from a hydraulic lift. After collection, acorns are commonly tested for soundness by water flotation (*1, 6, 7*). Floating acorns are usually considered unsound and discarded. Although this simple float test has been used for years, to our knowledge it has not been tested experimentally.

Materials and Methods

Experiment 1. On September 28, 1982, we collected acorns from a single northern red oak tree in Oneida County near Rhinelander, WI. Acorns were mature and were beginning to fall from the tree. We collected newly fallen acorns from the ground, and then spread tarpaulins under the tree and shook acorns from the branches. Acorns were segregated into lots according to collection procedure and tested by water flotation. The presence of intact acorn cups was also noted. Not all acorns collected from the tree had intact cups; all acorns collected from the ground with cups intact floated in water. Five categories were recognized:

1. Ground-collected floaters with cups (GFC).
2. Ground-collected floaters without cups (GF).
3. Ground-collected sinkers (GS).
4. Tree-collected floaters (TF).
5. Tree-collected sinkers (TS).

Acorns were rinsed in captan fungicide to retard mold and then their surfaces were air dried. Lots of 50 acorns were stored in 4-mil polyethylene bags at 4 °C for 95 days, because red oak acorns require cold stratification to break embryo dormancy (*5*). Acorns were then removed from the cooler, allowed to warm to room temperature, and soaked in water overnight.

Germination was determined in January 1983 in a greenhouse bench filled with a 3:1 mixture of coarse perlite and sand (about 10 centimeters deep). Acorns were planted about 2 centimeters deep at 7.5 by 10 centimeters spacing, and the seedbed was maintained at 40 percent moisture content (oven-dry basis) at 22 °C. Artificial light (150-watt flood lamps) was provided daily from 8 a.m. to 4 p.m.

Experiment II. On September 7, 1983, we collected acorns with the aid of a hydraulic lift from another northern red oak tree near Rhinelander, WI. Acorns were collected from branches at four different heights in a 16-meter-tall tree: 1) 16 meters (top), 2) 12 meters, 3) 8 meters, and 4) 4 meters (bottom). Acorns from each stratum were kept separate and then floatation-tested. All sinking acorns were bagged and stored as in experiment I for 118 days.

Acorns were planted in January 1984 as in experiment I. The germination bed was lighted artificially for 16 hours per day from 6 a.m. to 10 p.m. and was watered with an intermittent mist system (i.e., 2-second misting every half hour).

Germination. Emergence of the epicotyl from the seed bed was used as an indicator of germination (3, 5). (Emergence percent is considered an indicator of germination percent throughout the paper.) Germinating acorns were counted and recorded three times a week for 6 to 7 weeks. Germination percent and peak value were used to quantify germination success. Peak value was proposed by Czabator (4) to express both the speed and completeness of seed germination. Peak value (PV) is equal to the maximum cumulative germination percent divided by the number of days from sowing.

Because germination percent data do not usually exhibit a normal distribution, these data were transformed with arcsine $\sqrt{\%}$ for analysis (9). Peak values were not transformed. Analyses of variance were conducted on transformed data in the case of germination percent and on raw data for the peak values. Linear contrasts (9) were used to compare treatments at weekly intervals over the duration of the experiment (table 1).

Table 1—*F-tests of significance of linear contrasts from analysis of variance of percentage germination data from northern red oak acorns at 5 weeks after planting (experiment I)*

Source of variation	Degrees of freedom	F-test	Significance[1]
Treatments	4	31.4	0.01
Ground-collected vs tree-collected acorns	1	6.4	0.05
Ground-collected sinkers vs floaters	1	17.8	0.01
Tree-collected sinkers vs floaters	1	2.0	NS
Cups vs no cups	1	99.2	0.01

[1] Transformed percentage germination data.

Table 2—*Germination rates of northern red oak acorns collected in 1982 and 1983 in Oneida County, WI*[1]

Treatment	Peak value ± SE
Experiment I	
Tree-collected sinkers	4.1 ± 0.4 a
Ground-collected sinkers	3.4 ± 0.5 a
Tree-collected floaters	3.3 ± 0.5 a
Ground-collected floaters	1.6 ± 0.3 b
Ground-collected floaters w/cups	0.1 ± 0.1 b
Experiment II	
16-m-high branches	1.9 ± 0.3 a
12-m-high branches	1.9 ± 0.2 a
8-m-high branches	1.6 ± 0.1 a
4-m-high branches	1.8 ± 0.2 a

[1]Peak values calculated according to the methods of Czabator (4) and Bonner (1984). Peak values for each experiment followed by the same letter are not significantly different at the .05 probability level.

Results and Discussion

Germination percentages of northern red oak acorns varied greatly with acorn collection procedures and with water flotation (fig. 1). After 5 weeks, germination in experiment I had stabilized and ranged from 2.5 to 85.0 percent. Tree-collected acorns had a significantly higher germination percent than ground-collected acorns (table 1). But "sinkers" had a high germination percent regardless of where they were collected. Although tree-collected sinkers had the highest germination percent, the difference in germination percentage was not significantly different from ground-collected sinkers (fig. 1). Tree-collected sinkers did, however, have a peak value higher than the ground-collected sinkers (table 2), indicating that they germinated more rapidly (4).

Surprisingly, the germination rate of tree-collected floaters was over 70 percent and was not significantly different than the rates for ground-collected sinkers or tree-collected sinkers. Ground-collected floaters had a germination percent and peak value much lower than the ground-collected sinkers and

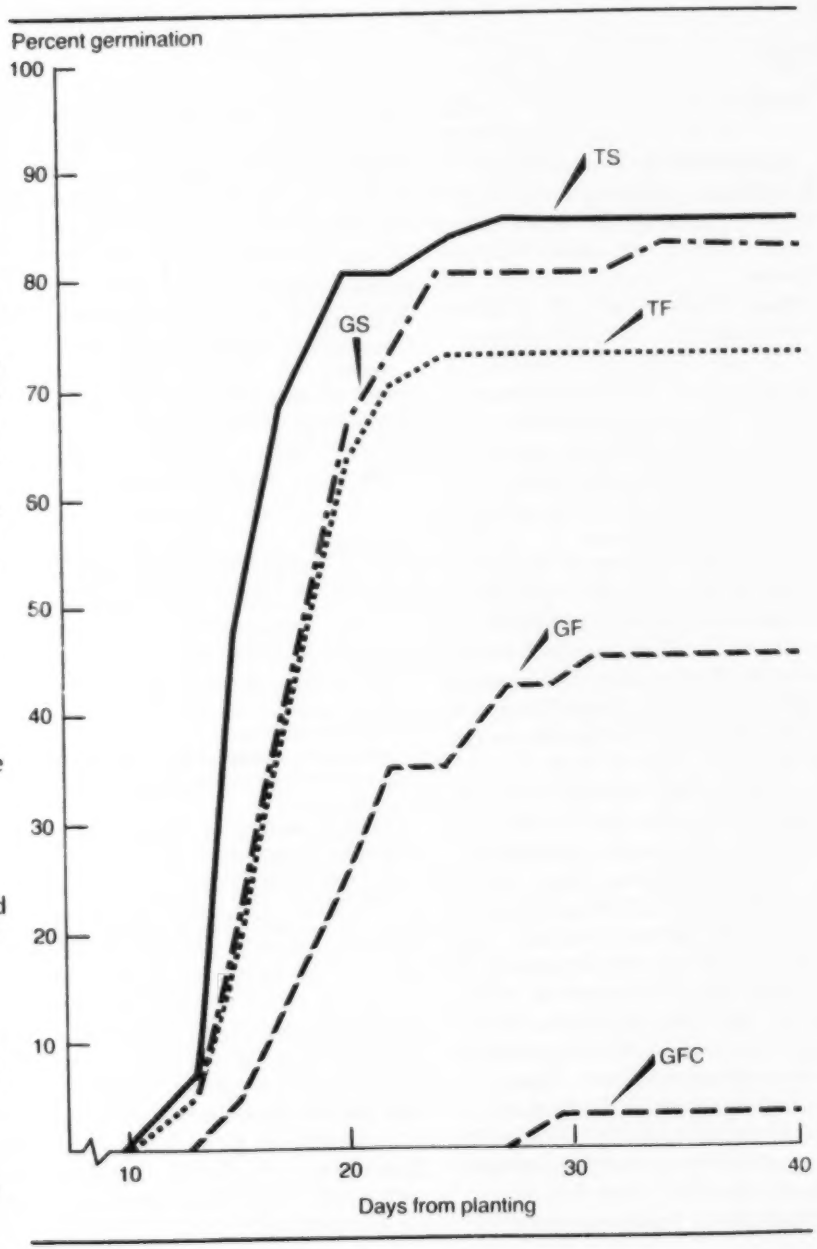

Figure 1—*Percent germination of northern red oak acorns over time after various collection procedures and water flotation. TS = tree-collected sinkers, GS = ground-collected sinkers, TF = tree-collected floaters, GF = ground-collected floaters, and GFC = ground-collected floaters with cups. Acorns were collected in Oneida County, WI, in 1982.*

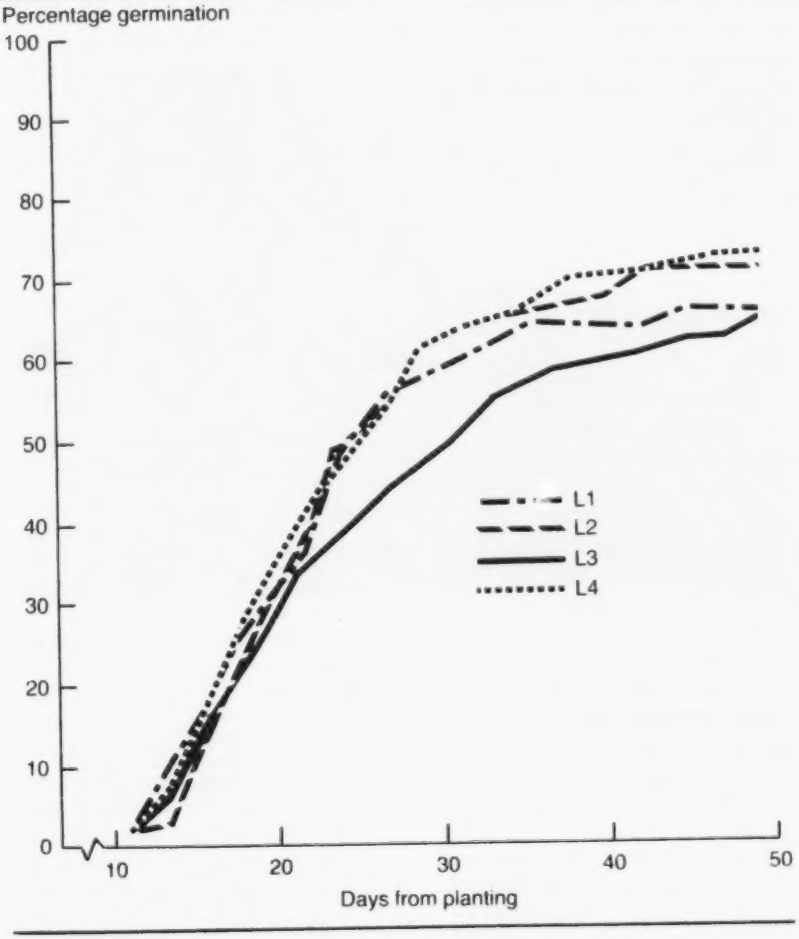

Figure 2—*Percent germination of acorns collected from branches at four heights in a northern red oak tree. L1 = 16-meter-high branches (top); L2 = 12-meter-high branches; L3 = 8-meter-high branches; and L4 = 4-meter-high branches (bottom). Acorns were collected in Oneida County, WI, in 1983.*

even the tree-collected floaters. The fact that tree-collected floaters germinated better than ground-collected floaters is important, because it means that foresters have an additional source of viable acorns, particularly in poor seed crop years. To our knowledge the distinction between tree and ground floaters has not been made previously.

Ground-collected floaters without cups had a much lower germination percent (< 50 percent) and germinated much slower than either the sinkers or the tree-collected floaters (table 2). Ground-collected floaters with cups germinated poorly, and are not likely to germinate in either a natural or artificial environment.

Acorns in 1983 had lower germination percents (fig. 2) and lower peak values (table 1) than acorns from the first study tree in 1982. Despite the fact that all acorns in experiment II were tree-collected sinkers, their germination percent ranged from only 65 to 73 percent in 7 weeks which was somewhat lower than in 1982. However, location within the tree made no significant difference in either germination percent or peak value (fig. 2; table 2). It should be noted that this was a vigorous, young tree growing in a mixed hardwood stand. Older trees growing under different stand conditions may not produce such a uniform crop of acorns.

The reason for the lower germination percents and peak values in the second experiment may be the fact that the acorns were collected from a different tree, during a different year. Including more trees in the study may have helped answer this question. However, this is an example of the kind of variation that foresters who collect acorns routinely face due to the uncer-

tainty of acorn crops from tree to tree and from year to year (*8*). The acorns in experiment II may have been collected slightly before their maturation date, because many were just beginning to turn brown and had not yet separated from their cups (*2*).

Conclusions

Our findings should be helpful to foresters and nurserymen who wish to propagate oak, particularly in poor seed years. Acorn collection and handling procedures can affect both the percentage and rate of germination of northern red oak seed. Tree collection of acorns can be made from all portions of the red oak crown, and acorns should be collected after they lose their green color just before separating from the cup. Tree collection is recommended for best germination.

Acorns that sink during water flotation are the most viable regardless of whether they are collected before or after falling from the tree. Thus, we recommend water flotation for all acorn collections. Surprisingly, tree-collected floaters without cups also germinate well, but ground-collected floaters without cups do not. Ground-collected floaters with their cups intact have little or no germination capability.

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The Aquarium Tester—A Fast, Inexpensive Device for Evaluating Seedling Quality

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Materials and methods for a hydroponic test of root growth potential are described, and the technique is used to evaluate Douglas-fir (Pseudotsuga menziesii *(Mirb.) Franco) seedlings that were outplanted in the southern Cascade mountains.* Tree Planters' Notes 37(3):13–16; 1986.

The Medford BLM District has been evaluating a method of hydroponically determining the quality of its lots of lifted Douglas-fir seedlings prior to planting. With this method, samples of at least 15 seedlings from each lot to be tested are removed from the newly delivered bags and boxes and the roots placed in simple 10-gallon aquariums (fig. 1). After 14 days, new root growth is readily apparent and measurable, and the quality of the stock can be evaluated by counting the number of new root tips 1 centimeter and longer.

The significance of this aquarium root growth was evaluated last summer in the field in a formal research study in which the seedling survival of nursery lots was compared with contrasting levels of seedling root growth. The first year results indicate that a positive and notable correspondence exists between the number of new roots produced in 14 days in the aquarium test and field survival of seedlings from the same lots. An inexpensive practical method to help users evaluate the quality of their seedlings prior to outplanting is outlined in the article that follows, along with the results of the research study we implemented.

Figure 1—*Aquariums with aerators and seedlings installed.*

Constructing the Aquarium Tester

Materials for the construction of one aquarium tester can be purchased for under $65.00 (table 1). Access to a band saw and drill press reduces labor and construction time. If these tools are not

Table 1—*Materials for the construction of the aquarium tester*

Materials	Quantity	Approx. cost ($)
10-gallon glass aquarium	1	15.00
¼-inch-thick Plexiglas top (12 by 20 inches)	1	9.00
Air pump	1	6.00
Air pump tubing per foot	5	.50
Aerator stone	1	1.00
#11½ black rubber stopper	15	15.00
Aerosol paint can	2	3.00
Glass tube aquarium heater	1	5.00
Total cost		62.50

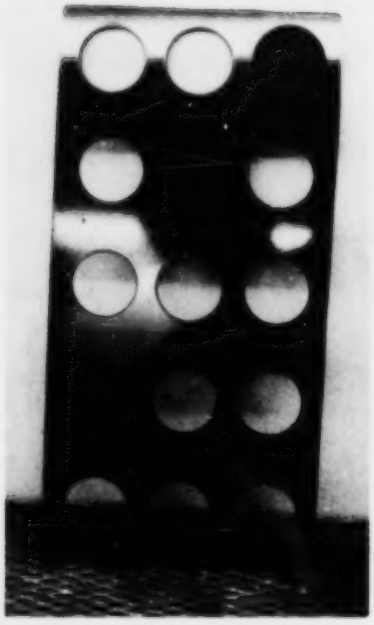

Figure 2—*Painted Plexiglas aquarium cover with 2¼-inch holes and rubber stoppers.*

available, a hand-held half-inch drill, a vise or clamps, a circular or band saw, a 2¼-inch hole saw, and a hacksaw will suffice.

Obtain a piece of Plexiglas approximately 12 by 20 inches and trim with the band saw or circular saw to fit the inside lip at the top of the tank (fig. 2). Do not use plywood; it warps, allowing light to enter the tank easily. Using the hole saw, cut up to fifteen 2¼-inch holes in which to insert rubber stoppers. A half-round file may be needed for smoothing any rough edges. At some point on the edge of the lid, cut or drill notches for the air tube and aquarium heater to enter the tank. The top should be painted black to keep out light. Lightly sand the Plexiglas top to help paint adhere.

Clean the outside glass surfaces of aquarium thoroughly before painting so that paint will adhere. Black electrical tape may be used to cover seams and missed spots. Take care to ensure that paint does not come in contact with the underside of the lid or inside of the aquarium, for toxic substances in the paint may harm the seedlings.

Turn the tank upside down and paint it. Cut a line in the stoppers from the outside edge to the center hole so that the seedlings can be inserted.

Once the paint is dry, fill the tank with fresh water and connect the air pump. A small air pump has the capacity to aerate one tank. Use fresh water in a thoroughly sterilized apparatus (liquid bleach works well) each time a test is run. Attach the aquarium heater and set it to maintain a minimum water temperature of 68 to 70 °F at least 1 day prior to placing seedlings in the tank.

Be careful not to damage the bark or cambium layers when inserting the seedlings in the stoppers (fig. 3). Tight center holes should be enlarged, and seedlings smaller

Figure 3—*Plexiglas cover with rubber stoppers and seedlings installed.*

than the holes can be held in place with cotton wool.

After 14 days in the aquarium, remove the seedlings and clip all new white roots over 1 centimeter long. Roots can be quickly removed with clipper or fingernail. Count and measure roots from all seedlings and divide by the number of test seedlings to establish the root growth class for the seedling lot (table 2). Although correlation between these classes and subsequent seedling performance is tentative, planting recommendations are listed in table 2.

Table 2—*Root growth classes and subsequent performance*

Class	Description*	Planting quality
0	No new growth	Dead or very poor—do not plant
1	Some new roots, none over 1 cm long	Dead or very poor—do not plant
2	1 to 3 new roots over 1 cm long	Poor to fair—plant on low-stress sites only
3	4 to 10 new roots over 1 cm long	Good quality—plant on typical new sites
4	11 to 30 new roots over 1 cm long	Excellent—plant on droughty sites
5	30+ new roots over 1 cm long	Superior—plant on toughest sites

*From Burdett (1).

Root Growth Potential Test

Thirty Douglas-fir seedlings produced from certified seed of the same seed source but grown at two different west Cascade nurseries (15 seedlings from each) were tagged and randomly placed in two aquarium testers on April 5, 1985. Root growth was visually evaluated 2 weeks later (fig. 4), but seedlings were left in the tanks for an additional week (for a total of 3 weeks) before the final evaluation and clipping on April 26. Little or no root growth was noted after the previous inspection.

The evaluation indicated that the seedlings produced by nursery A had a range of 1 to 4 new root tips that were 1 centimeter and longer per seedling, with an average of 2.33 roots per seedlings; this corresponds to root growth class 2—poor to fair. For nursery B, the number of new roots ranged from 1 to 16 per seedling, with an average of 7.4. This corresponds to root growth class 3—good quality.

Figure 4—*Douglas-fir seedling roots after 14 days in tank. Class 4 = 11 to 30 new roots measuring over 1 centimeter.*

Outplanting Trial

Four hundred 2–0 bareroot seedlings from nursery A and nursery B (200 each) were planted by skilled planters on April 4, 1985, at a test site in southern Cascade mountains north of Butte Falls, Oregon. The planting layout followed a randomized complete block design with four replications on a tractor-scarified and ripped south-facing clear-cut (slope less than 30 percent) at 3,240 feet in elevation. The site had been operationally planted the previous year with survival exceeding 90 percent. No gopher damage nor deer browsing was observed on the previously planted seedlings, and very little grass was present, but heavy infestations of bull thistle developed in the summer of 1985. This competition may have affected variation in survival among replications, making detection of the effects of seedling quality on survival more difficult. Survival was measured twice during 1985; in August and

in late October. Percent survival of seedlings from nursery A was 81 percent in August and 50 percent in late October as compared to nursery B with 90 percent and 66 percent at those times.

Discussion

In this study, differences in seedling root growth for the two nursery lots were congruent with first-season seedling survival in the field. Seedlings with the lower root growth potential, as measured by the aquarium tester, performed more poorly after outplanting. Observations of operationally planted seedlings from the two nursery lots involved corroborates the root growth and field survival test; the seedling lots with the lower root growth survived less well. In addition, the general appearance and condition of the surviving seedlings at the end of the first growing season was notably better for the seedling lots that tested better in the aquariums.

Conclusion

Determining the root growth potential of Douglas-fir seedlings hydroponically may have some potential as a predictor of seedling quality prior to planting. Articles and publications by Ritchief (*5*), McCreary and Duryea (*4*), Stone and Jenkinson (*8*), and Burdett (*1*) indicate that root growth potential is positively correlated with first-year survival and growth. Using this method, measurable results may be obtained in 14 days, compared to the 25- to 45-day period required by the growth chamber method of potting seedlings and evaluating subsequent bud break and flushing (*2*).

Other advantages of this method are that no growth chamber is necessary, root growth is visible, roots are easily accessible and easily measured, and there is no loss of new root tips in the growing medium. Further testing is necessary to more precisely define the relationship between water temperature of the aquarium and the minimum time before measurement, the best minimum length of new root tips to count, and the closeness of the relationship between the classes and field performance of the seedlings. With development of the aquarium tester, however, foresters and other nursery users, with minimal investment, can begin to evaluate their seedling stock while it is still in the cooler, and also help answer some of the questions posed above.

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Nutrient Concentration Effects on *Pisolithus tinctorius* Development on Containerized Loblolly Pine (*Pinus taeda* L.) Seedlings

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A trade-off between seedling size and degree of mycorrhizal infection needs to be considered when determining the rate at which to fertilize containerized seedlings infected with ectomycorrhizae. Tree Planters' Notes 37(3):17–22; 1986.

Ectomycorrhizae can increase forest tree survival and growth under many different site conditions (*11*). Mycorrhizae increase tree root surface area, increase the absorption of water and nutrients, and can exploit forms of phosphorus (P) unavailable to nonmycorrhizal plants (*1*). *Pisolithus tinctorius* (Pers.) Coker & Couch is a fungus capable of forming ectomycorrhizae on trees growing on acidic, droughty, and infertile soils. It has been used successfully for improving the performance of pines on reclaimed surface mines (6) and on clay soils in North Carolina and Georgia (4).

Much work has been done on methods for inoculating pines with *P. tinctorius* basidiospores (*5, 8,* 9). Using spores is more convenient and less costly than inoculating with vegetative fungal mycelia. Marx and co-workers (7) found that ectomycorrhizal development was related to soil fertility, with nitrogen (N) and P being the most critical nutrient elements. At high N and P concentrations, *P. tinctorius* infection of loblolly pine appears to be reduced. Lower *P. tinctorius* infections coincide with lower levels of sucrose in the roots. On the other hand, Lamb and Richards (3) found that greater mycorrhizal infection of Monterey pine (*Pinus radiata* D. Don) and slash pine *Pinus elliottii* Engelm. on Australian soils occurred when P was applied. The objective of this study was to examine the relationship between nutrient levels and *P. tinctorius* ectomycorrhizal development on container-grown loblolly pine seedlings.

Materials and Methods

P. tinctorius fruiting bodies were collected in the fall from a 20-year-old loblolly pine (*Pinus taeda* L.) stand in Buchanan County, VA. Basidiospores were harvested, suspended in water, and added to vermiculite and peat (1:1, v/v) that was being mixed in a cement mixer. Spores were applied at a rate equivalent to 250 grams per hectare. Spencer-Lemaire Rootrainers (Hillson model, 150 cubic centimeter per cavity) were filled with this mixture and two loblolly pine seeds of Virginia Piedmont origin were placed in each container. After germination, seedlings were thinned to one per container.

Four replications (eight seedlings per replication) of five nutrient solution levels (treatments) were used in this study (table 1). The five treatments consisted of a serial dilution of reagent grade chemicals. Molar ratios of 1:1.2:1.1:0.3 for KNO_3, NH_4SO_4, H_3PO_4, and Fe (as Greenol), respectively, were used to provide the various amounts of nutrients. A serial dilution was used to establish treatment levels so that the most concentrated treatment was 16 times as concentrated as the lowest fertilization rate (table 1). Nutrients were added in 15 milliliters of water every 2 weeks. Additional watering occurred on a regular basis.

Table 1—*Amount of nitrogen, phosphorus, potassium, and iron added every 2 weeks during the 20-week study period*

	Amount of nutrient (mg)			
Solution level	N	P	K	Fe
1×	0.25	0.16	0.21	0.09
2×	0.50	0.32	0.42	0.18
4×	1.00	0.64	0.84	0.36
8×	2.00	1.28	1.68	0.72
16×	4.00	2.56	3.36	1.48

After 20 weeks, seedlings were harvested. The degree of mycorrhizal infection was calculated as the number of individual short roots colonized, divided by the total, and expressed as a percentage. Roots and shoots were separated at the root collar, dried to a constant weight at 65 °C, and weighed. After weighing, needles were stripped from the stems and composited by replicate for foliar N and P analyses. Foliar N was determined by the Kjeldahl technique (*2*). Phosphorus was extracted with 6 *N* HCl from 0.5 gram of tissue, following dry-ashing at 450 °C. Phosphorus was determined by the Murphy-Riley ascorbic acid technique (*13*). Regression techniques were used to analyze the data (*12*).

Results and Discussion

Fertilizer concentration had a significant effect on degree of infection, shoot weight, root weight (figure 1) and on foliar N and P concentrations (figure 2). The highest rates of fertilizer resulted in larger seedlings, but mycorrhizal colonization was greatest at the lower rates. Maximum root system colonization was about 30 percent, which decreased to about 10 percent at the highest fertilizer level.

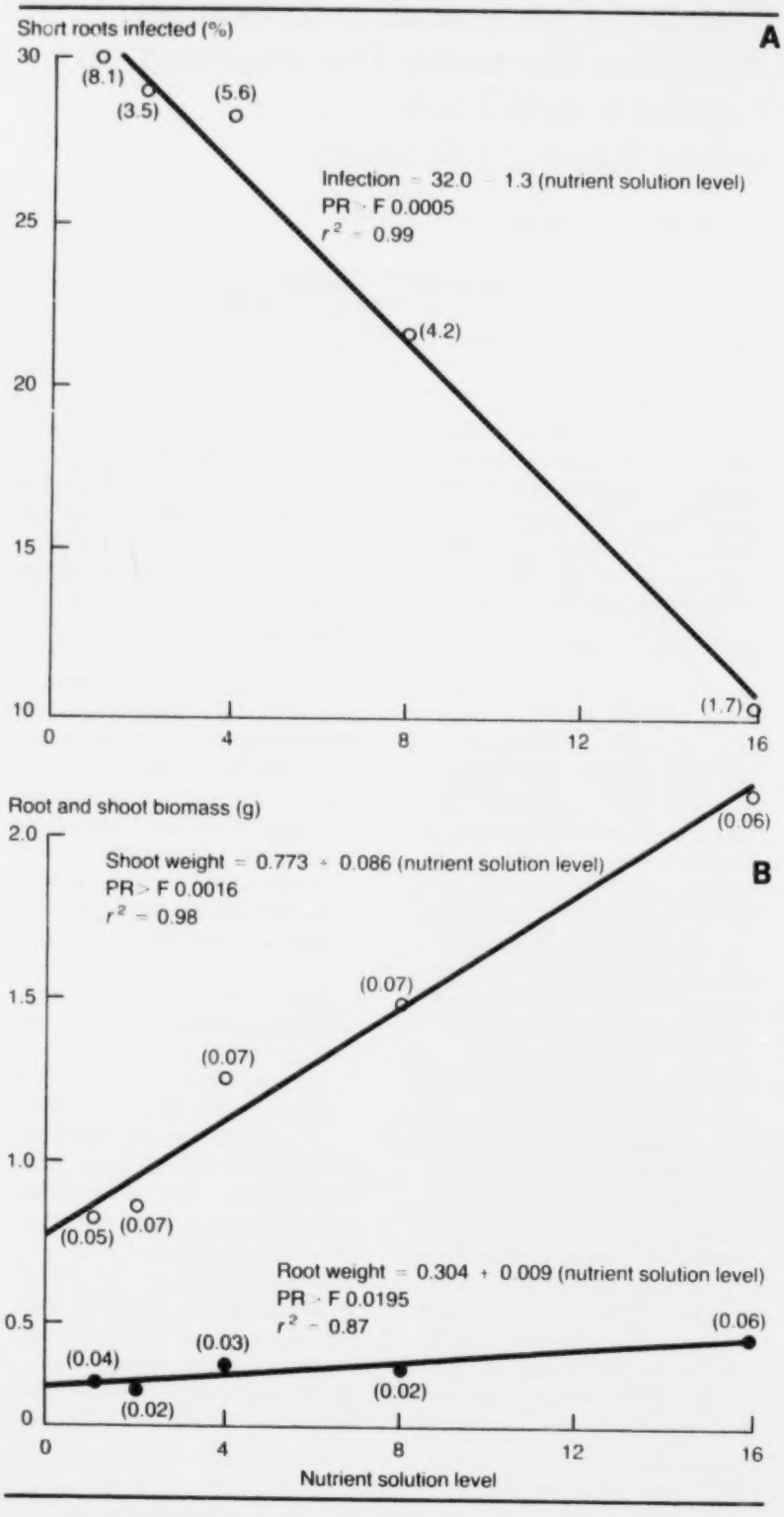

Figure 1—*Relationship between mycorrhizal infection (***A***), seedling biomass (***B***), and nutrient solution level. Numbers in parentheses are standard deviations.*

Foliar nutrient levels increased with fertilizer rate (figure 2). In the most concentrated treatment, foliar N and P levels were 1.02 and 0.14 percent, respectively. Although the N/P ratio (1.56 milligrams per milligram) in the nutrient solution was greater than the N/P ratio (1.21) used by other researchers (*9*, *10*), there seemed to be insufficient N even at the highest treatment level. Nitrogen is generally considered deficient when foliar levels are below 1.2 percent, whereas 0.1 percent is a commonly accepted critical level for P (*14*).

There were also significant relationships between foliar nutrients and seedling biomass and infection (figures 3 and 4). Shoot weight increased but root infection decreased with increasing foliar N and P levels. Seedling size continued to increase as foliar P levels rose above 0.1 percent. This can be explained by the fact that N was limiting but P was available in sufficient quantities. Additional increments of N and P then resulted in luxury consumption of P, while seedling growth was still responding to added N.

Although root weight was used as a measure of root size, an estimate of total root length or surface area would have been more meaningful. There were distinct morphological differences observed

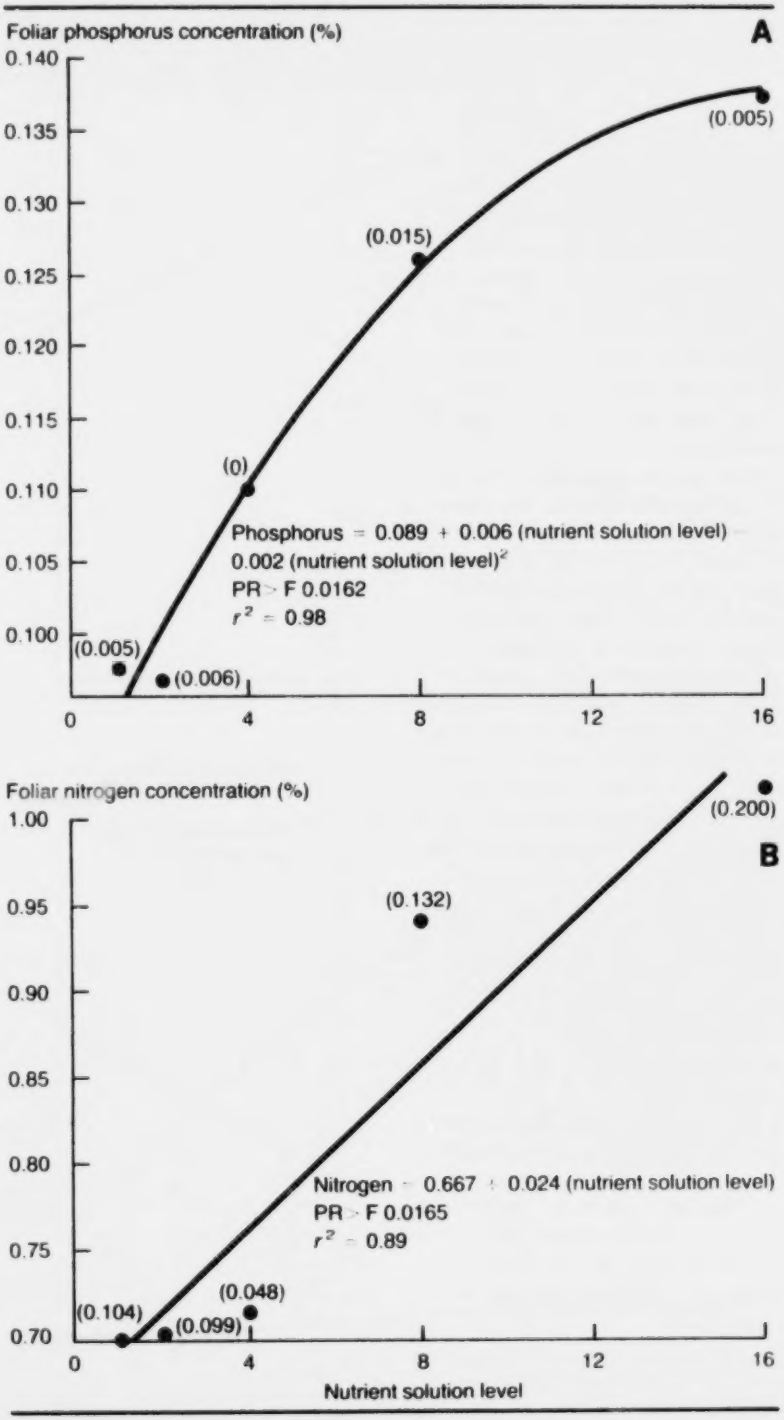

Figure 2—*Relationship between foliar phosphorus (**A**) and nitrogen (**B**) and nutrient solution level. Numbers in parentheses are standard deviations.*

between root systems at different nutrient levels. Root systems of seedlings receiving the highest treatment were short and stocky. Although they weighed less, the root systems subjected to lower nutrient levels were longer, more fibrous, and had a greater degree of branching.

In order for seedlings to survive in harsh environments, they need an adequate root system to absorb moisture and nutrients. Seedlings receiving the greatest amount of nutrients in this study, although larger, could be at a disadvantage when outplanted. They would require greater amounts of moisture to meet the demands of their larger foliar biomass, but their root systems had a smaller surface area and less absorptive capacity. The likelihood that the smaller trees receiving the lowest levels of nutrients would be more successfully established is increased by the greater degree of mycorrhizal infection.

Conclusion

Although nutrients are necessary to develop healthy containerized seedlings, it appears that there is an optimal level above which additional nutrient supplies produce seedlings that may be more sensitive to drought and less able to

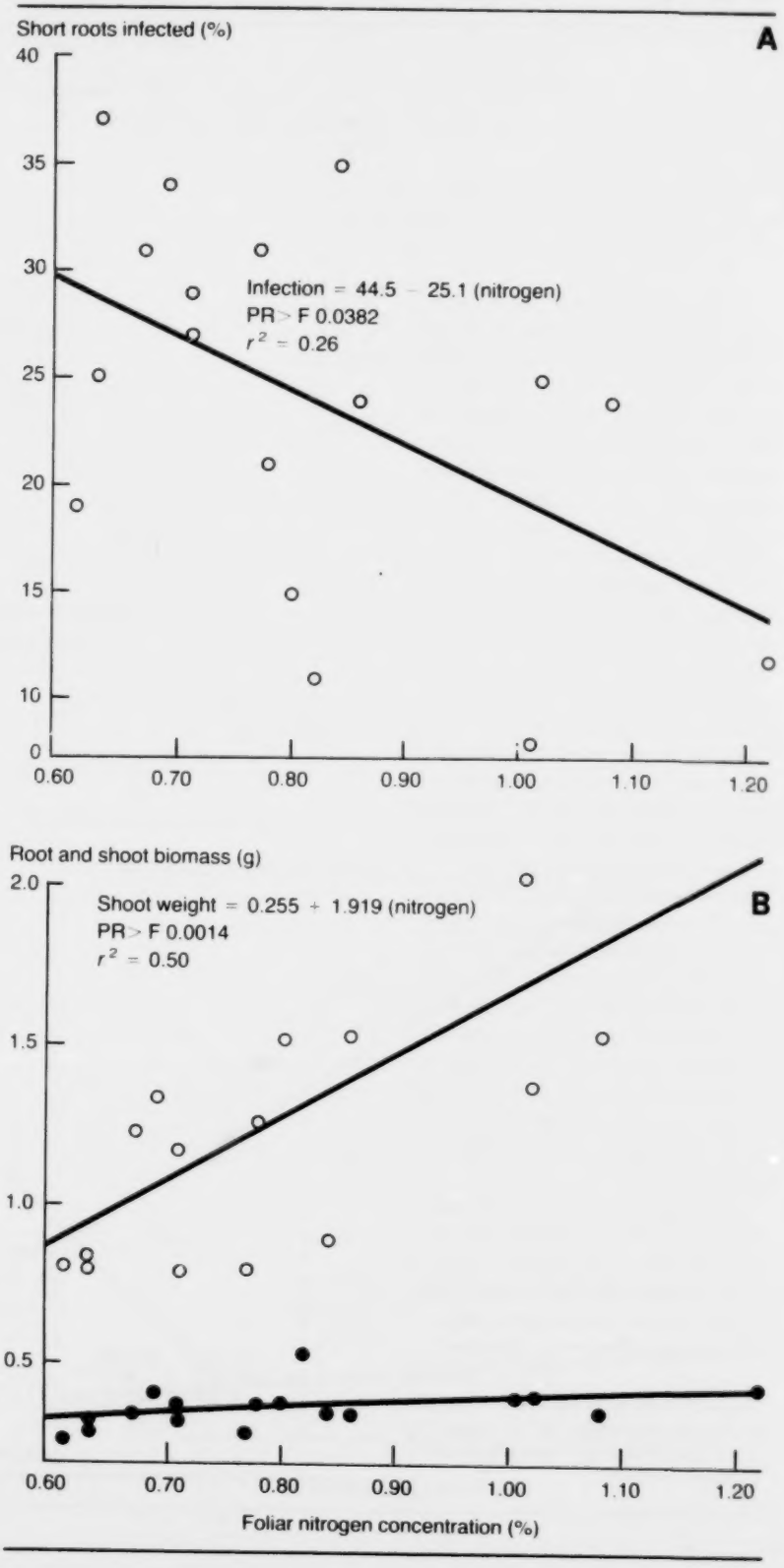

Figure 3—*Relationship between mycorrhizal infection (**A**), seedling biomass (**B**), and foliar nitrogen concentration.*

adapt to stress. Seedling size, root system morphology, and mycorrhizal colonization need to be optimized. An ideal fertilization program might be one that allows the seedlings to attain just enough N and P to reach foliar levels considered adequate for good growth. At higher levels, mycorrhizal infection is reduced and root systems undergo morphological changes resulting in smaller surface areas. In this study, level 4 × (1.0 milligram N, 0.6 milligram P, and 0.8 milligram K) may represent the best level of nutrient supplementation because infection is still high and seedlings are significantly larger than those receiving lower levels of nutrients. Ultimately, seedlings should be outplanted to determine how these morphological and physiological properties affect establishment and early growth.

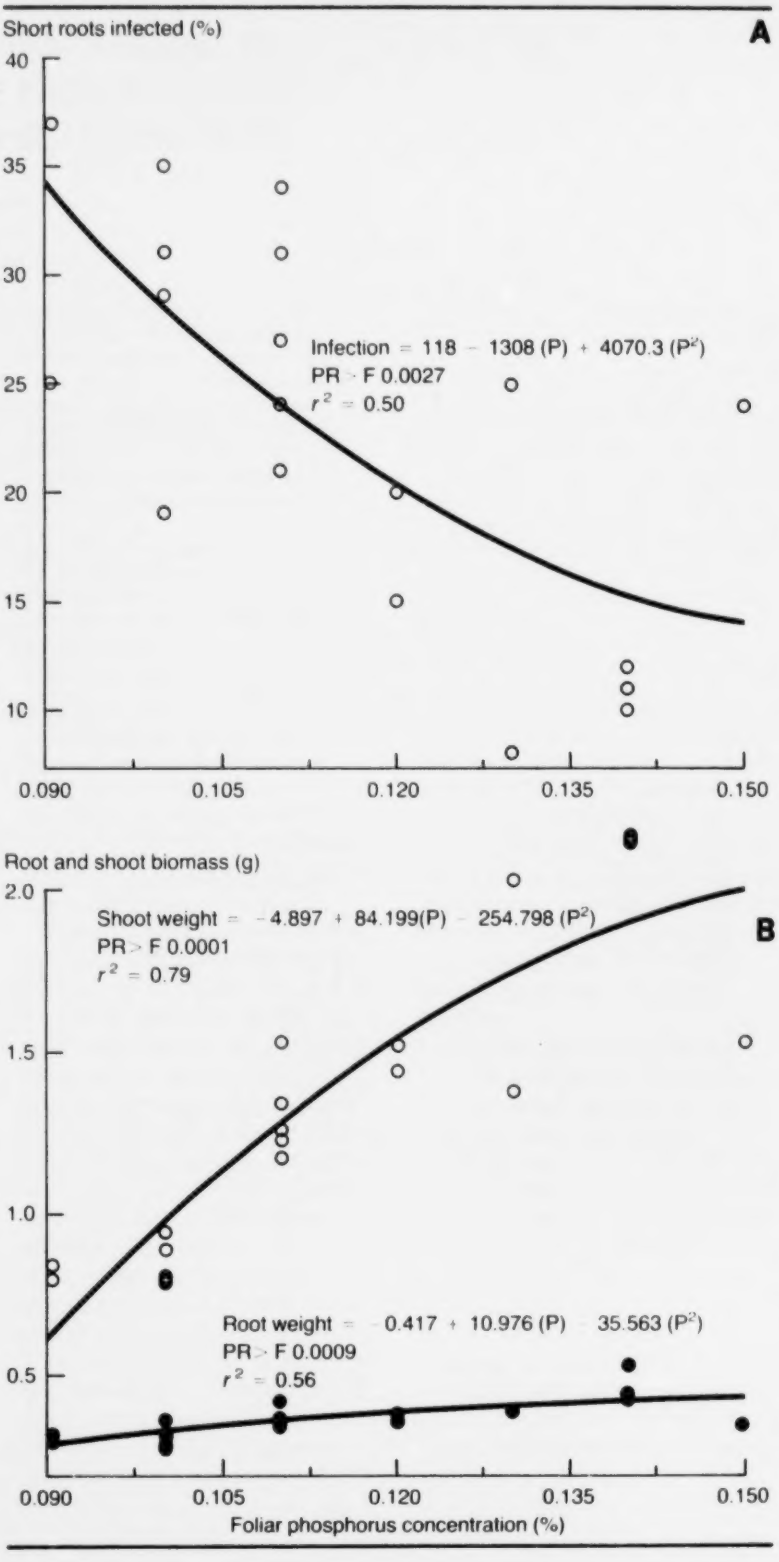

Figure 4—*Relationship between mycorrhizal infection (**A**), seedling biomass (**B**), and foliar phosphorus concentration.*

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Pine Plantation Survival Related to Calculated Moisture Deficits on the Huron National Forest (1929–1976)

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Soil moisture deficits are an important cause of seedling mortality on the sandy outwash plains typical of the Huron National Forest. Red and jack pine planting survival records from 1929 through 1976 were examined, and those years with two or more planting sites and consistent survival were chosen for study. Growing-season water deficit, expressed as the difference between precipitation and potential evapotranspiration, was significantly related to percentage survival using simple linear regression. Survival ranged from 30 to 95 percent, while moisture deficits ranged from +0.40 to −8.31 inches during the growing season. With a mean moisture deficit of −3.82 inches during the growing season, the expected seedling survival is 80 percent. Based on available water contents in the sandy outwash soils, moisture deficits commonly exist during the growing season, and site preparation and planting practices should attempt to preserve surface organic layers. Tree Planters' Notes 37(3):17–22; 1986.

Obtaining acceptable survival of planted pine seedlings is often a challenge for regeneration foresters. Although competition with neighbors and pest attacks are the chief causes of mortality of older trees (*2*), a myriad of factors, including stock quality and handling, soil moisture and nutrient conditions, seed source, and pests influence planted seedlings (*1*). Proper attention to these details and appropriate planning for the reforestation effort have proven to be useful in reducing seedling mortality (*5*).

Of the many site factors that influence seedling survival, soil moisture is often critical. This fact has been well-documented for a number of tree species, including Douglas-fir (*7*), ponderosa pine (*6*), and loblolly pine (*3*).

The Huron National Forest has had an active reforestation program for over 55 years, and because of the sandy, droughty, glacial outwash soils that are common on the forest, much attention has been paid to the relationship between soil moisture and seedling survival. Several years ago an investigation was begun to determine if seedling survival could be adequately predicted by soil moisture or some other readily measurable climatological factor. A prediction equation would be useful to determine how much of the variation in seedling survival is attributable to soil moisture/climatological factors and how much remaining variation is attributable to other factors. Planting site management recommendations may be varied on certain sites to preserve organic matter, prohibit prescribed burning, or modify site preparation and planting practices.

Methods

First year planting survival records for the Huron National Forest were examined for the years 1929 through 1976. The survival data base consisted of those years for which there were two or more red pine and/or jack pine planting sites with consistent survival. The planting seasons selected represented 137 planting sites, 8,576 acres, and approximately six million seedlings.

Climatological data from the U.S. Department of Commerce, Environmental Science Services Administration was obtained for the study years, and potential evapotranspiration (PET) was calculated using the method of Thornthwaite (*10*). Thornthwaite's method for computing PET integrates the factors of vapor pressure, temperature, wind, humidity, evaporation, and transpiration and involves a series of calculations using monthly temperature values (*9*). Veihmeyer (*11*) presented Thornthwaite's equations as follows:

$$PET = 1.6 \cdot \frac{10\,T^a}{TE} \quad (1)$$

$$a = 0.000000675(TE)^3 - 0.0000771(TE)^2 + 0.01792TE + 0.49239 \quad (2)$$

$$i = T^{1.514} \div 5 \quad (3)$$

where:

PET = potential evapotranspiration (cm)

T = mean monthly temperature (°C)

TE = temperature − efficiency index, equal to the sum of 12 monthly values of heat index, *i*.

In order to compute PET for a given location:

- mean monthly temperature (T) is used to compute a heat index *i* using equation 3
- the heat indexes are summed over a year to obtain a temperature − efficiency index (TE)
- the temperature − efficiency index is used to compute the variable a using equation 2
- mean monthly temperature (T), temperature − efficiency index (TE), and the variable a are used in equation 1 to compute PET
- the PET computed by equation 1 may be adjusted for daylength and number of days per month (because the number of days per month varies between 28 and 31 and the number of hours of active evapotranspiration per day varies with latitude) (4).

A plot of monthly PET and precipitation is commonly used to display a water balance for a given location.

There is a water deficit when PET exceeds precipitation. If the soil moisture is depleted during this period, seedlings may die. Moisture deficits were calculated for the growing season months of May through August for each year and were used as an independent variable in a simple linear regression analysis with percentage seedling survival as the dependent variable.

Results and Discussion

Water deficit during the growing season and percentage seedling survival were significantly ($P<0.01$) related as follows:

$$\%\ \text{survival} = 99.1137 - 5.3836\ (\text{water deficit in inches}) \quad (4)$$

$$r = -0.795$$

$$SE = 12.2\%$$

Although many factors, such as competition for sunlight, insect and disease damage, limited soil nutrients, and poor stock quality and handling, also contribute to seedling mortality, calculated moisture deficit during the growing season was correlated with percent survival on the Huron National Forest (table 1). During 1934 the growing season moisture deficit was −8.31 inches, and during 1940 a moisture surplus of +0.40 inches occurred. On the average the moisture deficit during the growing season was −3.82 inches, however. Seedling survival ranged from 30 percent in 1933, when there was a moisture deficit of −7.00 inches, to 95 percent in 1940.

Equation 4 is used to predict expected survival rates at varying moisture deficits. Table 2 displays the actual and expected survivals, as well as the relative occurrence of moisture deficits during the 47-year study period. Eighty-four percent of the years had moisture deficits between 0.0 and −5.0 inches. Actual and expected survival rates were in reasonable agreement except at the −7.0 moisture deficit, which had only a 30 percent seedling survival. For that year some factor other than moisture must have contributed heavily to seedling mortality. According to Ohms (*8*), a seedling survival rate of 70 percent is normal for the Lake States region, assuming good quality planting stock and proper planting procedures. A water deficit of about −5.0 inches should result in about 73 percent of seedlings surviving their first year. Water deficits below −5.0 inches may result in objectionable levels of mortality.

Thornthwaite's PET equation is useful for integrating the climatic factors of precipitation, temperature, wind, relative humidity, and evapotranspiration into a reliable

Table 1—*Descriptive statistics of regression data*

	Growing-season moisture deficit[1] (in.)	Percentage seedling survival
Mean	−3.82	80
Range	−8.31 to +0.40	30 to 95
Standard deviation	2.96	20

[1]Computed as the sum of the moisture deficits (precipitation − PET) for May through August

Table 2—*Actual and expected survival and relative occurrence during the study period for various moisture deficits*

Growing-season moisture deficit (in.)	Relative occurrence during study period (%)	Percent survival	
		Actual	Expected
−10	2	—	45
− 9	0	—	51
− 8	4	58	56
− 7	2	30	61
− 6	8	—	67
− 5	11	86	72
− 4	11	83	78
− 3	15	92	83
− 2	25	90	88
− 1	11	91	94
0	11	95	99
+ 1	0	—	100

index that is significantly related to seedling survival. In addition, PET can be used to indicate specific periods of moisture stress. The dominant soils planted to red and jack pine on the Huron National Forest are Typic Udipsaments of the Grayling, Graycalm, and Rubicon series. The average available water content for these soils is 5 percent, and the bulk density ranges from 1.3 to 1.7 grams per cubic centimeter for the surface 10 inches.

The available water holding capacity is computed by multiplying the percentage of available water content by the bulk density by depth of the horizon. Therefore, the available water holding capacity for the surface 10 inches ranges from 0.65 to 0.85 inches. The 47-year mean daily PET's for the months of May through August for the Huron National Forest are 0.09, 0.14, 0.15, and 0.12 inches, respectively. Therefore, the available soil water would be depleted in May in 7.2 to 9.4 days, in June in 4.6 to 6.1 days, in July in 4.3 to 5.7 days, and in August in 5.4 to 7.1 days. Unless the top 10 inches of soil gets recharged during these time limits, the planted seedlings will experience moisture deficits with a resultant increase in mortality.

Summary

Agencies and organizations that are heavily involved in artificial regeneration recognize the importance of factors such as proper stock handling, correct planting practices, planting site condition, and soil moisture to early seedling survival. The simple linear regression equation presented here has proven useful in providing expected seedling survivals at various moisture deficits. If the survival rate is less than expected during a season with a relatively low moisture deficit, other factors may be implicated. Although foresters are unable to manipulate climatic conditions, and irrigation is infeasible, other site preparation practices such as preserving surface organic layers while removing competing vegetation may aid in reducing evapotranspiration losses.

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Survival and Coverage by Several N_2-Fixing Trees and Shrubs on Lime-Amended Acid Mine Spoil

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Acid mine spoil was amended with agricultural-grade lime ($CaCO_3$) (0.0, 12.5, 25, and 39 tons per hectare) and planted with Alnus glutinosa *(European alder),* Caragana aborescens *(Siberian peashrub),* Elaeagnus umbellata *(autumn olive),* Myrica pensylvanica *(northern bayberry),* Robinia fertilis *'Arnot' (bristly locust),* Robinia pseudoacacia *(black locust), and* Shepherdia argentea *(silver buffaloberry). Addition of lime caused significant linear increases in soil pH. To maintain a pH above 5.5, 39 metric tons per hectare were required because of the acidic nature of the mine spoil. Survival of plant material was greatest at the highest lime addition, although responses of individual species varied.* Elaeagnus umbellata, R. pseudoacacia, R. fertilis *'Arnot', and* A. glutinosa *appeared more tolerant of the harsh conditions. Total coverage and growth (projected biomass) was proportional to the amount of added lime for all species except* R. pseudoacacia, R. fertilis *'Arnot', and* M. pensylvanica. *The two* Robinia *species showed no response above 25 tons per hectare and* M. pensylvanica. *The two* Robinia *species showed no response above 25 tons per hectare and* M. pensylvanica *performed best at lower pH.*
Tree Planters' Notes 37(3):27–31; 1986.

Strip-mine spoil banks can be one of the most hostile environments for plant establishment and development, generally because of extremes in pH, texture, and slope (*13*). Soil temperature, low water-holding capacity, and nutrient status can also be limiting factors but are generally correctable.

In midwestern and eastern mine spoils, pH values as low as 2.2 have been recorded (*1*). Extreme acidity is generally the result of acid clays, sandstones, or shale or of the oxidation of pyrite to sulfuric acid (*17, 18*). Lime treatments may provide only short-term increases in pH because of the constant oxidation of sulfur-containing compounds (*5, 19*). Spoils with pH values less than 4.0 are generally considered toxic to most plants (*18, 19*).

Struthers and Vimmerstedt (*15*) believed that reclamation of mine sites would be more rapid and successful if methods were directed toward basic land improvement rather than superficial landscaping. They held little promise in the search for more tolerant plant species. A large number of species trials have been conducted on disturbed land over the years (*7–9, 14, 15*). Criteria for selecting plants for mine reclamation include suitability for drastic site conditions (pH, drought, low fertility, etc.) and the ability to rapidly develop long-term site cover. Additional considerations are soil enrichment, wildlife cover, and economic productivity (*13, 14*).

A number of woody nitrogen-fixing species have shown promise or are currently used for mine reclamation. These include *Alnus glutinosa* (L.) Gaertn. (*3, 11, 13*), *Elaeagnus angustifolia* L. (*14*), *E. commutata* Bernh. ex Rydb. (*14*), *E. umbellata* Thunb. (*10, 13, 14*), *Robinia fertilis* Ashe. (*13, 16*), and *R. pseudoacacia* L. (*3, 4, 7–10, 12*). Nitrogen-fixing trees and shrubs offer excellent possibilities for low maintenance and potentially productive perennial mineland cover. Some site amendment will be necessary to ensure survival of plants, and selection of species must be coordinated with site conditions. Organic matter has been shown to increase and surface temperatures to moderate as trees and shrubs increase in size (2).

This moderating effect favors establishment of other, less tolerant species. Nitrogen-fixing woody species could be combined with grass–legume cover crops and possibly other long-term forest crops to develop a total plant community on disturbed sites.

Materials and Methods

The site of the study was a surface coal mine in southwest Indiana that had been returned to original contour and was being revegetated. Several pH samples

were taken to ensure as nearly a consistent pH as possible for the experimental areas. Lime requirements were determined using the SMP buffer pH method (6). Because of the extremely low initial pH (2.85) and the acid nature of mineland spoils, SMP lime rates were 0, 12.5 (low), 25 (medium), and 39 (high) metric tons of $CaCO_3$ (agricultural-grade limestone) per hectare. Treatments were spread by hand and disked to a depth of 15 to 20 centimeters in perpendicular directions. Each plot (11 by 5.8 meters) was replicated four times.

Plots were planted with ten 1- to 2-year-old seedlings of *A. glutinosa*, *Caragana arborescens* L., *E. umbellata*, *M. pensylvanica* Lois., *R. fertilis* 'Arnot'. *R. pseudoacacia*, and *Shepherdia argentea*. Plants were nodulated at the time of planting, and legumes were reinoculated with commercial *Rhizobium* preparations. Seedlings were planted at a spacing of 90 by 120 centimeters on April 26, 1977. Soil was tested and plant survival observations were taken on May 19, June 14, August 23, and September 21, 1977, and May 5, and July 7, 1978. Soil pH was determined using 2.5:1 (water/soil).

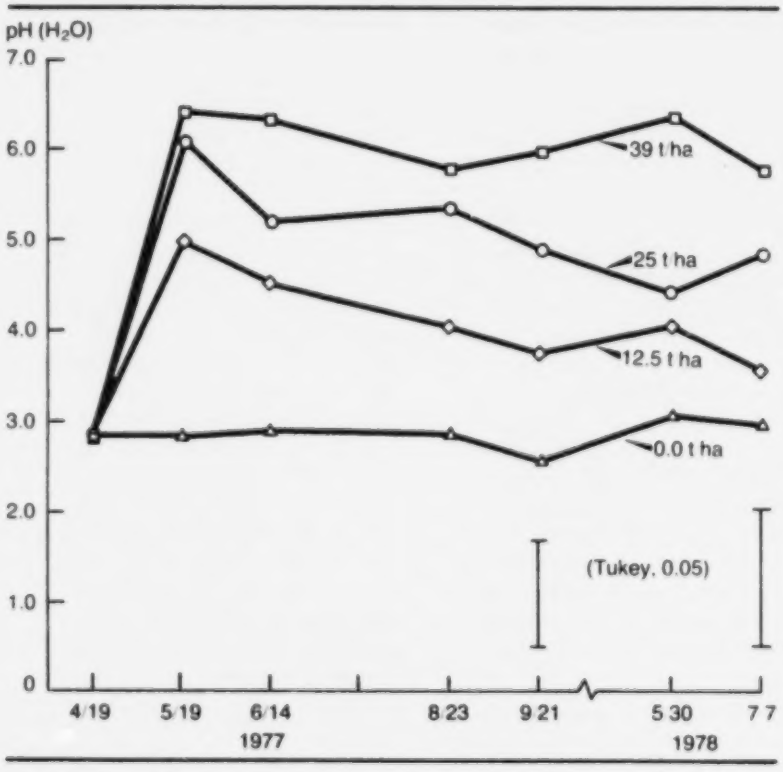
Projected biomass was determined by multiplying the average dry weight of plant tops from a maximum of five representatives from each replicate by the number of survivors in a given species. Dry weights of tops were measured after drying at 80 °C for 5 days.

Figure 1—*Increased soil pH as a result of lime ($CaCO_3$) addition. $CaCO_3$ amendment is given to metric tons per hectare. Vertical bar represents significant mean separations (Tukey-hsd, 5%).*

Results and Discussion

The addition of lime ($CaCO_3$) to acid strip-mine spoil raised the pH markedly, with the highest pH being achieved within 30 days of application (fig. 1). It required 39 tons per hectare to achieve a pH of 6.5 and maintain a pH of approximately 5.75 at 15 months after application. The medium and low lime treatments resulted in an increase in pH up to 6.1 and 5.0 initially, but these pH values declined to 4.8 and 3.5 after 15 months. Without lime, pH remained low (2.9).

Additions of lime maintained a relatively steady pH on acid mine spoils when amounts were adequate to overcome the constant



leaching of acid from the parent material. Lime applications that would be adequate for normal soils were able to provide only short-term pH adjustment against the constant acid leaching as indicated by the decline in pH values of low and medium lime treatments (fig. 1). The pH of 5.75 resulting from the high lime treatment is adequate for growth of most plants. Although pH might be expected to decline somewhat over time, additions of organic matter by the plants would aid the soil's buffering capacity.

Plant survival. Addition of increasing amounts of limestone to acidic mine spoil had a 97.2 percent linear correlation to survival of all species approximately 1 year after planting. This concurs with the suggestion by Struthers and Vimmerstedt (*15*) that reclaimed mineland spoils be modified to obtain good plant survival rates. However, some species appear more tolerant of the harsh conditions than others.

Robinia fertilis 'Arnot' and *R. pseudoacacia* were the only species to survive without the addition of lime (table 1); however, the individuals failed to grow and were essentially the same size as when planted. Survival rates of *R. fertilis* 'Arnot' and *R. pseudoacacia* (table 1), as with all species, were significantly increased with the addition of lime, but there was no statistical difference between higher and lower levels.

Survival of *E. umbellata* was high at all levels of lime addition (table 1). The 82 percent at the high lime treatment was greater than the 53 and 55 percent at the medium and low lime treatments, but not statistically because of variation within the replicates. Survival of *A. glutinosa* was greater at the high lime treatments (table 1) but was not statistically distinguishable from that at low lime treatments. The percent survival at the medium lime treatments was significantly less than at high but not at low lime treatment. *Caragana arborescens* and *S. argentea* responded to the high lime treatment with significantly greater survival (table 1). The low and medium lime treatments resulted statistically in the same low survival rates.

Survival of *M. pensylvanica* was poor at all lime additions (less than 50 percent) and was best, although not statistically, at the low lime treatment (table 1).

There was significant difference in the combined survival of all species at all lime levels (table 1). Poorest overall performance was by *M. pensylvanica* and best overall survival was by *E. umbellata*, *R. fertilis* 'Arnot', and *S. argentea*. Response of individual species varied with lime additions as demonstrated by the individual survival data. The highest lime application rate (pH 5.75) resulted in the highest survival rates for all species but *M. pensylvanica* (table 1). Survival of *S. argentea* was greatest but not statistically better than that of other species except *M. pensylvanica*.

Robinia fertilis 'Arnot', *E. umbellata*, and *S. argentea* survived best at the medium lime treatment (pH 4.8) (table 1) but were not significantly different from other species, except *M. pensylvanica*.

Regardless of the care taken to find homogeneous sites for the study, some variation with the replicates prevented detection of discrete statistical differences among the majority of the species at given treatment levels or differences

Table 1—*Effects of lime ($CaCO_3$) supplementation on survival nitrogen-fixing species planted on acid mine spoil*[1]

	Percent survival				
Species	0.0	Low lime (12.5 t/ha)	Medium lime (25.0 t/ha)	High lime (39.0 t/ha)	Average
Elaeagnus umbellata	0 c	53 b z	55 ab z	82 a z	48 z
Robinia fertilis 'Arnot'	21 b	37 ab z	60 a z	63 a yz	46 z
Shepherdia argentea	0 c	26 bc z	53 ab z	87 a z	42 yz
Alnus glutinosa	0 c	43 ab z	28 bc yz	77 a z	37 yz
Robinia pseudoacacia	9 b	30 ab z	38 ab z	63 a yz	35 yz
Caragana arborescens	0 c	17 bc z	30 b yz	60 a yz	27 yz
Myrica pensylvanica	0 a	33 a z	13 a y	27 a y	18 y

[1] Data collected on July 7, 1978. Mean separations by Tukey-hsd, 5%. Values within a row (a, b, c) or column (z or y) followed by different letters differ significantly.

within the responses of individual species to lime additions. *Elaeagnus umbellata, R. fertilis* 'Arnot', and *R. pseudoacacia* performed well at all amended pH levels. Insect infestation was noted on *R. pseudoacacia* the first season after planting and was more severe during the second season. There was no insect damage evident on any other surviving species in the study.

Projected biomass. Projected biomass is meant to provide an index of growth and ground cover associated with species and treatments within this study. It was calculated from actual dry matter data for species within a replicate and/or top dry weights of representative samples multiplied by the number of individuals surviving within the replicate. It is expressed as grams per square meter.

The mean biomass for all species had a 97 percent linear correlation with lime additions (table 2). *Elaeagnus umbellata* achieved the greatest projected biomass of any species at all lime additions and showed a linear correlation of 95 percent for increased growth with increasing lime level (table 2).

Shepherdia argentea and *A. glutinosa* showed 99 and 97 percent linear correlations, respectively, between projected biomass accumulation and lime additions (table 2). *Alnus glutinosa* responded dramatically to the high lime treatment (39 tons per hectare).

Robinia pseudoacacia and *R. fertilis* 'Arnot' (table 2) responded nearly identically in projected biomass development with lime additions. Both provided minimal cover on unamended sites, responded dramatically to the medium lime treatment, and declined slightly in the high lime treatment.

Myrica pensylvanica provided greater growth and cover at the lowest lime additions (12.5 tons per hectare) (table 2). However, there was statistically no difference between treatment means.

Table 2—*Effects of lime supplementation on mean projected biomass of nitrogen-fixing species planted on acid mine spoil*[1]

Species	Mean projected biomass (g/m^2)				
	0.0	Low lime (12.5 t/ha)	Medium lime (25.0 t/ha)	High lime (39.0 t/ha)	*r*
Elaeagnus umbellata	—	16.9 b	73.0 a	79.0 a	0.95
Robinia fertilis 'Arnot'	3.0 b	4.3 b	36.0 a	30.2 a	—
Robinia pseudoacacia	0.1 b	3.0 b	38.4 a	32.7 a	.86
Alnus glutinosa	—	8.8 b	10.4 b	23.7 a	.97
Caragana arborescens	—	4.2 c	6.2 b	18.7 a	.94
Shepherdia argentea	—	8.2 a	11.8 a	19.4 a	.99
Myrica pensylvanica	—	11.2 a	2.0 a	2.9 a	—
All species	0.41 b	8.1 b	25.4 a	29.5 a	.97

[1] Mean separation by Tukey-hsd, 5%. Values within a row followed by different letters differ significantly. Correlation coefficients (*r*) less than 0.90 are not listed.

Conclusions

Applications of agricultural-grade limestone had significant effects on the pH of acid strip-mine spoil and on the survival and projected biomass of the legume and nonlegume nitrogen-fixing species tested. Liming is the minimum site modification necessary for plant survival and growth. The pH of the spoil after all lime treatments dropped steadily, and only the 39 tons per hectare treatment maintained the pH above 5.0. Constant acid leaching from the parent material necessitates the use of massive quantities of neutralizing materials. Split or additional applications may prove necessary, if feasible, to maintain pH within plant tolerance ranges on some sites.

Lime applications or pH increases were required for the survival of most and the growth of all species. Survival was greatest at the highest lime applications; however, response of individual species varied. *Elaeagnus umbellata, R. pseudoacacia, R. fertilis* 'Arnot', and *A. glutinosa* appeared to be more tolerant of the harsh conditions. Survival was generally good to fair, even at the lowest lime

treatment, which resulted in spoil with a pH below the 4.0 considered toxic for most species. *Caragana arborescens* and *S. argentea* appeared to survive best if pH can be maintained near 6.0. *Myrica pensylvanica* survived better at lower lime applications, but its survival rate was generally poor at all treatment levels.

Total coverage and growth, as measured by projected biomass, was proportional to lime applications in all species except *R. pseudoacacia, R. fertilis* 'Arnot', and *M. pensylvanica*. *Myrica pensylvanica* performed best at lower pH and the two *Robinia* species showed no response at applications above 25 tons per hectare (pH 4.8).

Elaeagnus umbellata seemed to be a superior plant for the amended study site. *Robinia pseudoacacia, R. fertilis* 'Arnot', and *A. glutinosa* performed admirably and warrant inclusion in a total plant community. *Shepherdia argentea* and *C. arborescens* would appear more suitable on more extensively amended or less severe sites. Although survival of *M. pensylvanica* was low, its growth at low pH may warrant consideration in certain situations.

Although *R. pseudoacacia* is the most frequent nitrogen-fixing member of current plant communities on disturbed sites, it is not necessarily an ideal plant. Insect infestation had weakened the growth habit of the plants. While tolerance and survival may warrant continued usage, certain limitations for long-term and economic considerations should be weighed in comparison to other species.

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The Triple Bedformer—A Quick and Easy Method To Form Multiple Seedbeds

Steven D. Feigner and Frederick Zensen

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Attaching three bedformers to a large three-point yoke allows for more efficient use of equipment, operator, and nursery ground in seedbed preparation. Tree Planters' Notes 37(3):32–34; 1986.

The formation of raised seedbeds is an integral part of the tree nursery sowing operation. Raised seedbeds help promote warming of the seedbeds during the initial germination of seedlings and increase drainage. Most nurseries in the Pacific Northwest form raised beds for these reasons (Oregon State University Nursery Survey). The importance of having straight and correctly laid out seedbeds is twofold. Without properly laid out seedbeds, there is a high risk of constricting one or two of the beds to accommodate the irrigation lines that define the unit. Also, straight beds enhance equipment operation such as drill sowing, root pruning, and fertilization. However, the primary purpose in the development of the triple bedformer was to expedite the sowing operation.

At the J. Herbert Stone Nursery, sowing is accomplished with two seed drills operating simultaneously. This requires a good deal of coordination between the tractor operators preparing the seedbeds and the two seed-drill operators.

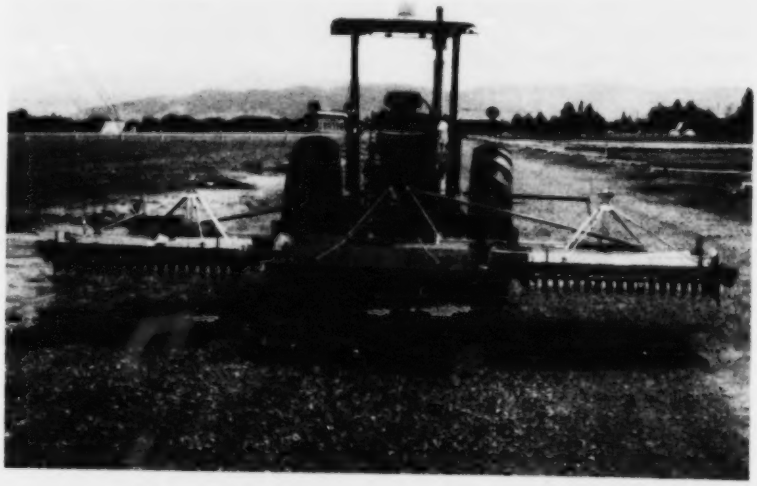

Figure 1—*The trip bedformer. Note protruding rods from bedformers that mark the beds.*

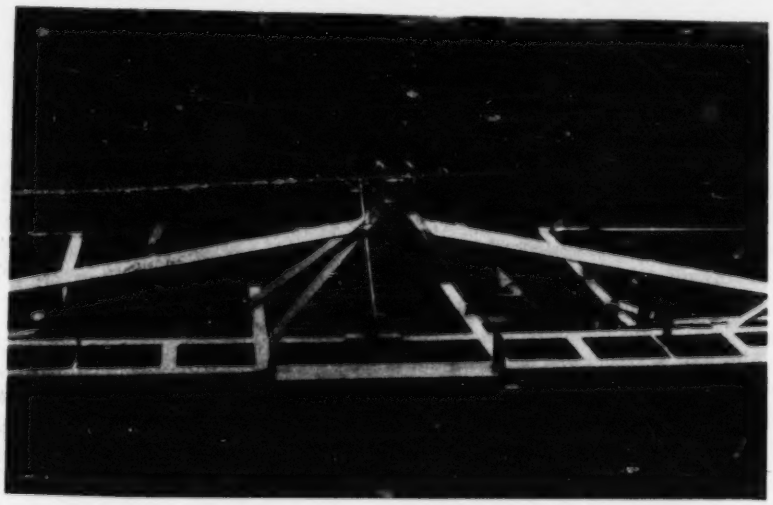

Figure 2—*Three-point hitch for triple bedformer.*

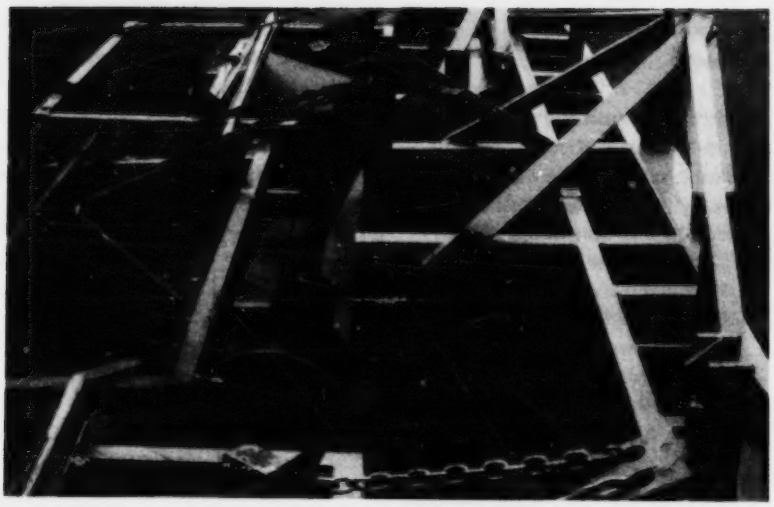

Figure 3—*Bedforming discs are offset.*

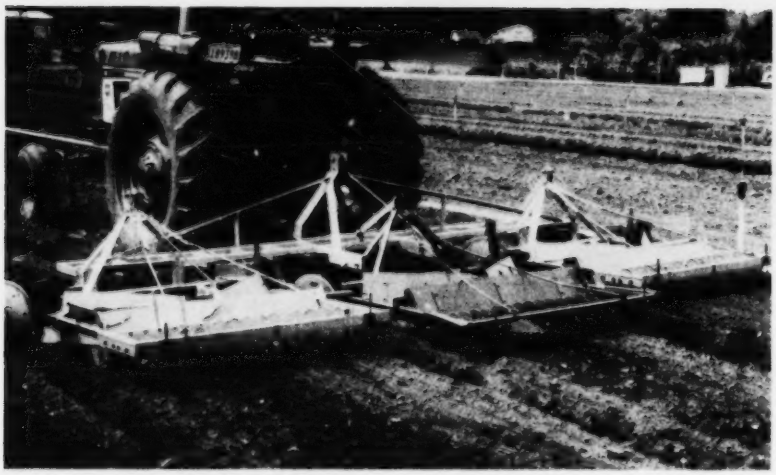

Figure 4—*Beds formed with triple bedformer.*

Therefore, a quick and efficient method of seedbed formation was of paramount importance.

Methods

Nurseries have used many different methods to form and mark beds, many of them homemade. Some nurseries rely on string lines, tractor-mounted bed markers, experienced tractor operators with "calibrated eyeballs," or sophisticated electronic equipment such as a laser. However, all of these methods have a common factor: they form only one bed at a time. In order to reduce the time required in seedbed preparation, personnel at the J. Herbert Stone Nursery developed the triple bedformer to form three seedbeds in one tractor pass.

Utilizing two Whitfield and one Larchmont bedformers, J. Herbert Stone Nursery personnel built and tested a triple bedformer (fig. 1). Bedforming implements as a rule are not extremely heavy, but there was some concern about the combined weight of three formers in addition to the newly constructed three-point yoke (fig. 2). Testing alleviated this concern. The middle former had to be placed further back than the outside two because the soil-scraping discs interfered with each other (fig. 3). The three

bedforming implements were attached to the yoke by means of individual three-point hookups welded on the main yoke. Guide markers were attached to the rear of each single implement.

A 40-horsepower Ford tractor used for the trial runs had no difficulties with lifting or pulling the triple bedformer. With adequate bracing and reinforcement, the implement was strong enough to perform well under field conditions (fig. 4).

Discussion

Multiple bedforming offers several advantages to single bedforming. Since only two passes are necessary to form an entire unit as opposed to six, an immediate savings of 66 percent is realized. Soil compaction is also reduced. The seedbeds formed with the triple bedformer are more straight and level than those formed by individual passes. Bed height is more uniform and path width is constant. Time spent bedforming was greatly reduced and string lines and row workers were eliminated, because irrigation pipelines served as guides.

Seed Stratification Treatments for Two Hardy Cherry Species

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Seed of Mongolian cherry (Prunus fruticosa Pallas) germinated best after 30 days of warm plus 90 days of cold stratification. Amur chokecherry (Prunus maackii Rupr.) was best after 30 days of warm plus 60 days of cold stratification. Longer stratification periods resulted in germination during storage. Tree Planters' Notes 37(3):35–38; 1986.

The genus *Prunus* contains many native and introduced species that are hardy in the Northern Plains and are used for shelterbelt, wildlife, reclamation, and ornamental plantings. Two relatively recent introductions from Asia are Mongolian cherry (*Prunus fruticosa* Pallas) and Amur chokecherry (*Prunus maackii* Rupr.).

Prunus fruticosa is placed in the subgenus Cerasus. It ranges from central and eastern Europe to Siberia and is rated as zone III in hardiness (*3*). It is a suckering, spreading shrub that grows to 2 meters in height and will form dense thickets. The leaves are a dark glossy green. The tart, dark red fruits measure about 1 centimeter in diameter and are utilized by wildlife and humans. Mongolian cherry may be used in outside row plantings in shelterbelts, recreational plantings, and wildlife plantings.

The seed-propagated selection 'Scarlet' Mongolian cherry (figs. 1 and 2) has recently been released by the USDA Soil Conservation Service for conservation purposes in the Northern Plains (*4*).

Prunus maackii is placed in the subgenus Padus. It ranges from Manchuria to Korea and is rated as zone II in hardiness (*3*). It is a non-suckering tree that grows to 15 meters in height. Its leaves are dull green. The dark purple fruits are borne in racemes and are utilized by wildlife. Amur chokecherry is often planted as an ornamental because of its copper-colored, flaking bark, but it could also be useful in wildlife and recreational plantings.

Information regarding seed propagation of these two species is limited. Initial late fall nursery seedings resulted in minimal germination the following spring but in satisfactory germination the second spring after planting.

Seed of *Prunus* species require a period of after-ripening to aid in overcoming embryo dormancy (*2*). Several species require a warm stratification period followed by cold stratification. It was believed that *P. fruticosa* and *P. maackii* might benefit from this. Researchers at the Morden Manitoba Experimental Farm found that germination of *P. fruticosa* seed may be affected by the time of fruit

Figure 1—*Growth form of 'Scarlet' Mongolian cherry (courtesy of USDA Soil Conservation Service Plant Materials Center, Bismark, ND).*

collection. Delayed harvesting of fruit improved germination and later ripening varieties had higher germination rates. This was attributed to incomplete embryo development within the seed (*1*). A warm stratification period should allow embryo development to take place.

We evaluated stratification treatments for overcoming dormancy in the seed of *P. fruticosa* and *P. maackii*.

Figure 2—*Foliage and fruit of 'Scarlet' Mongolian cherry (courtesy of USDA Soil Conservation Service Plant Materials Center, Bismark, ND).*

Materials and Methods

Fruit of *P. fruticosa* and *P. maackii* were collected when fully ripe in the summer of 1983. Pulp was removed by wet maceration and the seed were dried and then stored at 4 °C until removed for this study in January 1985.

Seeds of each species were then counted into lots of 100 for use in the stratification treatments. In a cutting test, 100 percent of *P. fruticosa* and 98 percent of *P. maackii* seed were sound.

Seed were stratified in damp peat moss in polyethylene bags for time lengths varying from 0 days warm + 60 days cold to 60 days warm + 120 days cold. Storage temperatures were 18 ± 2 °C for warm stratification and 4 °C for cold stratification. A total of 10 treatments plus a control treatment of 0 days warm + 0 days cold stratification were tested. Treatments of *P. fruticosa* were replicated three times; those of *P. maackii* twice.

At the end of each stratification period, seed were removed from storage and allowed to germinate at room temperature. Temperatures ranged from approximately 20 to 30 °C. Germination counts were made weekly and a total of 30 days was allowed for germination to take place.

Results

Prunus fruticosa and *P. maackii* seed responded with increased germination to combination treatments of warm and cold stratification as opposed to cold stratification only.

At 0 + 90 days stratification, 33 percent of *P. fruticosa* seed (table 1) germinated; at 0 + 150 days, 46 percent. With an addition of a 30-day warm treatment, the germination rate increased to 67.3 percent with 30 + 90 days. Longer cold stratification treatments resulted in germination and root elongation in storage, which would make mechanical seeding difficult. Substitution of a 60-day warm treatment for the 30-day warm treatment did not increase germination percentage and resulted in in-

Table 1—*Germination of* Prunus fruticosa *following stratification treatments and 30-day germination period*

Treatment	Germination per 100-seed lot	Total germinants in 3 lots	Percent germination
Control			
0 + 0	0	1	0.003
	0		
	1		
0 + 60	11	31	10.3
	8		
	12		
0 + 90	26	99	33.0
	31		
	42		
0 + 120	36	107	35.6
	35	Germination in storage	
	36		
0 + 150	39	138	46.0
	46	Excessive germination and root elongation in storage	
	53		
30 + 60	41	107	35.6
	29		
	37		
30 + 90	62	202	67.3
	74	Beginning radicle emergence; check at 75 days cold for germination	
	66		
30 + 120	68	207	69.0
	70	Excessive germination and root elongation in storage	
	69		
60 + 60	56	181	60.3
	64	Germination in storage	
	61		
60 + 90	66	201	67.0
	68	Excessive germination and root elongation in storage	
	67		
60 + 120	63	195	65.0
	69	Excessive germination and root elongation in storage	
	63		

creased germination in storage

Seed of *P. maackii* (table 2) showed a positive response to warm stratifiction followed by cold stratification. Germination rate after cold stratification ranged from 0 to 4 percent but increased to a high of 64 percent with a treatment of 30 + 60 days. As with *P. fruticosa*, the use of longer cold stratification or of longer warm stratification periods resulted in increased germination in storage.

Both species contained cracked endocarps on many of the seeds after the warm stratification periods. Germination, however, did not occur without the cold treatment.

Discussion

These results indicate that 30 days of warm stratification followed by 90 days of cold will increase germination of *P. fruticosa* when stratified seed are required for spring nursery planting. It is recommended that checks on the seed in storage begin at 75 days of cold to insure that excessive root elongation does not take place. If germination does begin, the storage temperature can be lowered to just above 0 °C to slow root elongation.

Prunus maackii requires a 30-day warm stratification period preceding the 60-day cold stratification for germination to occur. Cold

Table 2—*Germination of* Prunus maackii *following stratification treatments and 30-day germination period*

Treatment	Germination per 100-seed lot	Total germinants in 2 lots	Percent germination
Control			
0+0	1 1 2 0	1	0.005
0+60	1 3 2 5	8	4.0
0+90	1 1 2 2	3	1.5
0+120	1 0 2 0	0	0.0
0+150	1 2 2 1	3	1.5
30+60	1 60 2 68	128 Radicle emergence & some root elongation	64.0
30+90	1 61 2 53	114 Germinating in storage	57.0
30+120	1 54 2 52	106 Excessive germination & root elongation in storage	53.0
60+60	1 51 2 56	107 Germinating in storage	53.5
60+90	1 46 2 56	102 Germinating in storage	51.0
60+120	1 57 2 52	109 Excessive germination & root elongation in storage	54.5

stratification only resulted in unacceptable germination percentages.

A practical nursery approach would be early fall seeding of *P. fruticosa* and *P. maackii* when at least 30 days of warm weather are still expected. Beds should be mulched and kept evenly moist until winter freeze up occurs. Germination will then take place the following spring.

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Erratum

In "A simple method for determining a partial soil water retention curve," by W. A. Retzlaff and D. B. South, in the Fall 1985 (Vol. 36, No. 4) issue of Tree Planters' Notes, please note the following corrections: the legend to figure 2 (page 22) should read "centibars = (− 33.5 + 7.9)/volumetric water content."; the reference cited in the first paragraph of page 23 should be number 3; and delete the words "every day" from the first sentence of the second paragraph of the second column on page 23.

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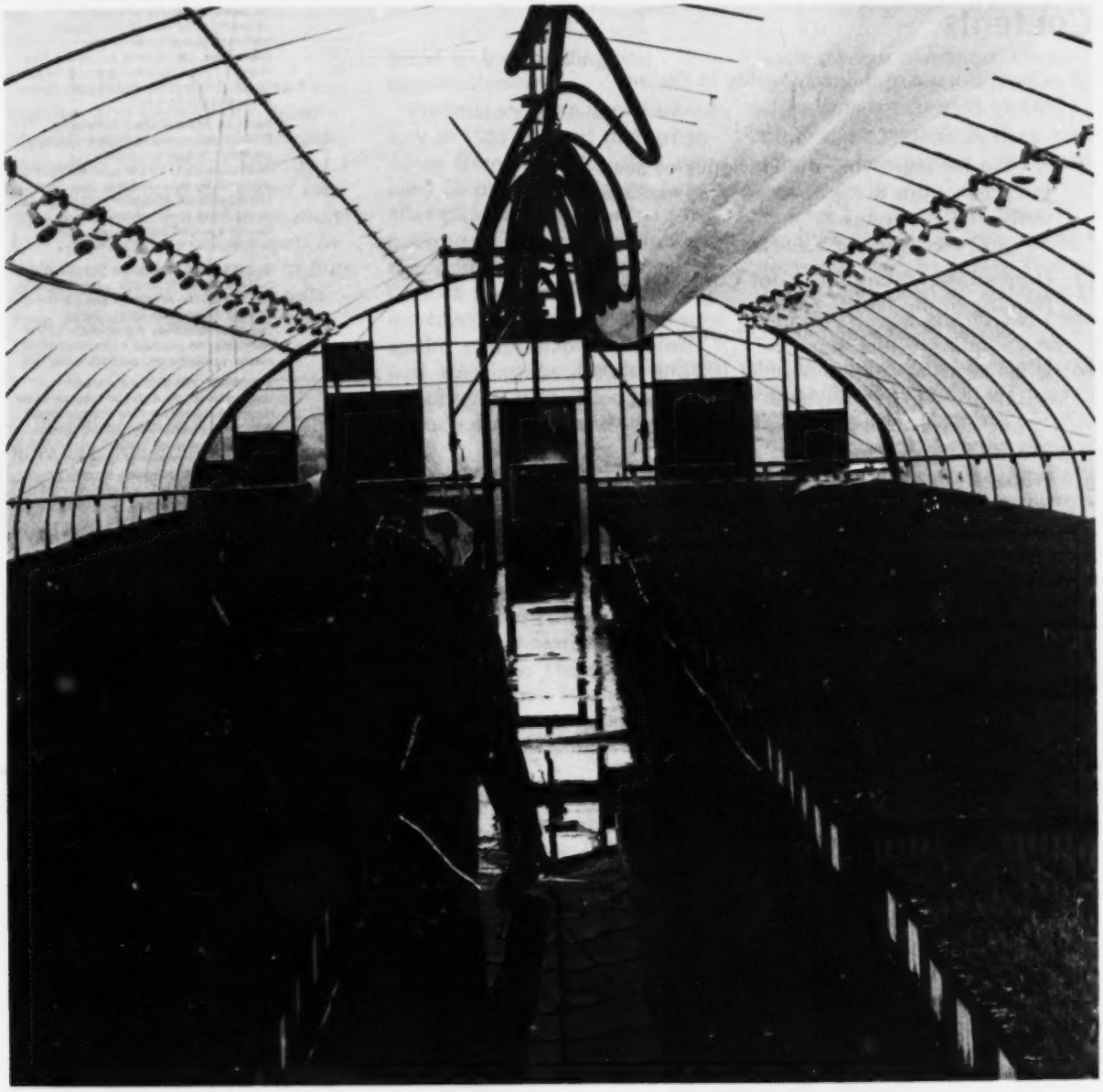

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Cover: Greenhouse at Couer d'Alene Nursery, Panhandle National Forest.

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Cone Storage and Seed Quality in Eastern White Pine (*Pinus strobus* L.)

F.T. Bonner

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USDA Forest Service, Forestry Sciences Laboratory,
Starkville, MI

*To achieve maximum seed extraction and germination from stored, immature cones of eastern white pine (*Pinus strobus *L.) the cones should be stored for about 1 week, or until cone moisture drops below 50 percent. Indoor and outdoor storage in burlap bags yielded similar results.*
Tree Planters' Notes 37(4):3–6; 1986.

Deciding when to collect and how to handle the cones of eastern white pine (*Pinus strobus* L.) has been a problem for many seed managers. Cone color can be used as a maturity index, and if demand for seed is low, it is possible to delay the collection until cones are a "straw yellow" color *(6)*. The increasing demand for white pine seed in the last 15 years, however, negates the use of cone color, because delaying collection until this color change occurs does not allow enough time to collect large quantities of cones before most of the seeds are disseminated. The best alternative is to use cone moisture content, estimated by specific gravity, as a maturity index. One study in Michigan showed that seeds were mature when cone specific gravities were in the 0.92 to 0.97 range *(5)*. However, cones picked with this much moisture must be handled carefully to avoid severe molding and case-hardening.

Preliminary tests at our laboratory in 1983 showed that green cones from North Carolina averaged 64 percent moisture 1 day after picking and were hard to open in ovens; germination was also poor *(3)*. Storing cones for up to 8 days before ovendrying improved cone opening and seed quality considerably. This test had used indoor storage only; a larger test was installed in 1984 to include outdoor cone storage.

Materials and Methods

Immature cones were collected from 5 to 10 trees in western North Carolina on August 11 and 12, 1984, by a contractor and delivered to the Forestry Sciences Laboratory at Starkville, MI, the following day. The cones were mixed, and two 5-cone samples were immediately taken to determine initial cone moisture content.

The remaining cones were placed in small burlap bags for storage under the following conditions:

(1) outdoors without protection,
(2) outdoors with overhead cover, but exposed to blowing rains, and
(3) inside small, unheated sheds or buildings with complete protection.

There were four replications of each storage condition. Cones stored outdoors (condition 1) were sprayed with hoses every other day to stimulate occasional rainfall when natural rainfall did not occur.

After 2, 5, 8, and 12 days of storage, 20-cone samples were removed from each bag. Five cones were used for determination of specific gravity and cone moisture and five cones were dried at each of three extraction temperatures (30, 35, and 40 °C) in forced-draft ovens.

The cones were dried in trays for 48 hours, then hit against a table top to remove the easily extracted seeds. The cones were then carefully torn apart by hand to recover all other seeds. The number of easily extracted seeds was expressed as a percentage of the total seeds for a measure of extraction efficiency.

The seeds were dewinged by hand, and germination was tested under standard conditions *(1)* following 56 days of stratification at 3 °C. The percentage of germination was based on filled seeds only. Analyses of variance were carried out using arcsine transformations of extraction efficiency and percent normal germination, and germination rate was expressed by peak value *(4)*. Differences among means were tested by Duncan's new multiple range test. All tests of significance were made at the 95 per-

cent level of confidence.

The specific gravity of cones was measured by water displacement *(2)*. Moisture contents were determined by weight loss of cones dried for 24 hours at 105 °C and were expressed as a percentage of fresh weight. Each of these cones was cut into three or four pieces with a cone cutter for the determinations.

Results and Discussions

Cone Moisture. The initial cone moisture content averaged 62.2 percent. The cones still had their green, vegetative color, and they did not open when placed in the drying ovens. The initial specific gravity of the cones was not measured, but it can be estimated as about 0.90 based on the relationship of specific gravity and cone moisture that was established with measurements taken during the storage test (fig. 1). The strong correlation between the two ($r = 0.9819$) illustrates how well moisture content can be estimated by specific gravity in eastern white pine cones.

During the storage period, cone moisture loss was about equal under all conditions for storage periods of 2 and 5 days (table 1). Rain on the seventh day kept outdoor cones high in moisture, but they lost moisture rapidly after that time. At 12 days, cones stored indoors had the highest moisture, 26.0 percent, while cones from the outdoor conditions had moisture levels of 17.6 and 12.3 percent.

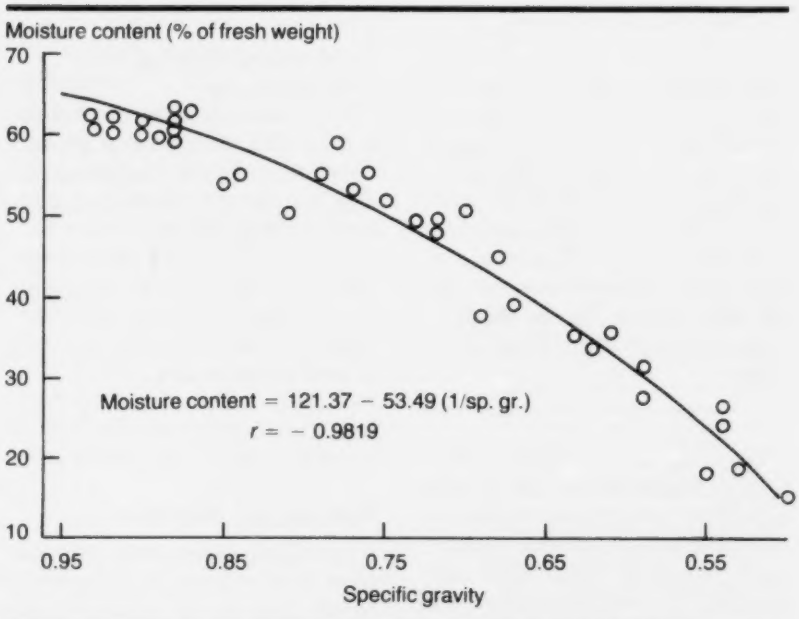

Figure 1—*The relationship of specific gravity to moisture content in cones of eastern white pine.*

Table 1—*Moisture content of cones stored for 2 to 12 days under three conditions (all percentages are based on fresh weight)*

Storage condition	Average moisture content (%)				
	0 days	2 days	5 days	8 days	12 days
Outdoors	62.2	61.2	52.2	48.1	17.6
Outdoors, covered	62.2	60.5	49.7	38.5	12.3
Indoors	62.2	61.0	55.4	36.7	26.0

Extraction Efficiency. Neither storage condition nor drying temperature had any significant effect on extraction efficiency (table 2); however, length of the storage period was very important. Extraction removed an average of only 13 percent of the total seeds after 2 days of storage and was best at 8 days (69 percent). The best extraction efficiency was

Table 2—*Extraction efficiency for cones of white pine stored for 2 to 12 days under different conditions and dried at three temperatures*[1]

Temperature (°C)	Extraction efficiency (%)				
	2 days	5 days	8 days	12 days	Mean
Outdoor storage					
30	18	41	35	61	38
35	35	61	86	56	60
40	26	41	87	63	55
Mean	26	48	71	60	51
Outdoor storage, covered					
30	1	34	72	62	38
35	7	55	76	44	44
40	11	65	72	41	46
Mean	6	51	73	49	43
Indoor storage					
30	12	60	59	69	49
35	18	56	66	64	51
40	5	63	65	66	47
Mean	11	60	63	66	49
Means[1]	13a	53b	69c	58b	

[1]Means followed by the same letter do not differ significantly ($P > 0.05$).

obtained after 8 days of storage (table 2), when cone moisture contents had fallen below 50 percent (table 1). Similar results had been obtained in the 1983 test *(3)*.

Cones allowed to dry to below 20 percent moisture while in storage did not open as well when heat was applied and had extraction efficiencies of only 60 and 49 percent, similar to values obtained in the 1983 test.

Germination. As with extraction efficiency, percentage total germination was not affected by the storage conditions but was significantly affected by the length of storage (table 3). Seed from cones stored only 2 days before extraction had significantly lower total germination than seed from cones stored for longer periods. The highest mean total germination was 75 percent after 8 days of storage, but it was not significantly better than the values for 5 to 12 days of storage.

Extraction temperature also had a significant effect. Seed from cones dried at 30 °C averaged only 56 percent of percentage total germination, whereas seed extracted at 35 °C averaged 77 percent. Germination of seed extracted at 40 °C was only 65 percent, significantly lower than the 77 percent at 35 °C.

Germination expressed as peak value (PV), the maximum cumulative percentage germination divided by the number of days from sowing *(4)*, followed the pattern of percentage total germination. Seed from cones stored only 2 days germinated at significantly lower rates than did seed from cones stored longer (table 3). The best extraction temperature was 35 °C; there was no difference between 30 and 40 °C. There was a significant interaction between storage period and extraction temperature; at 30 °C, the quality of extracted seed increased as the storage period increased from 2 to 8 days.

One remaining question is whether or not cone storage will affect the long-term storage potential of seed. Seed from this study are now in a storage test to provide the answer.

Conclusions

The data clearly show that immature white pine cones should be stored for about 1 week before heat is applied to the cones for seed extraction to obtain the best yields and seed quality. In this test, the best extraction rate was obtained after 8 days of storage, although seed quality was just as good from cones stored 5 to 12 days. Both indoor and outdoor storage were equally successful. Cone moisture content appears to be the key factor,

Table 3—*Germination of seeds extracted from cones of white pine stored for 2 to 12 days under different conditions and dried at three temperatures*

Temperature (°C)	2 days	5 days	8 days	12 days	Mean
Total germination (%)					
Outdoor storage					
30	30	55	51	67	51
35	70	85	86	79	80
40	64	52	67	74	72
Mean	54	65	69	73	66
Outdoor storage, covered					
30	12	54	76	62	50
35	71	66	92	73	76
40	42	81	75	57	64
Mean	40	68	82	64	64
Indoor storage					
30	52	74	66	78	68
35	74	79	77	62	73
40	59	75	74	50	65
Mean	62	76	73	64	69
Means[1]	52a	70b	75b	67b	
Peak Value					
Outdoor storage					
30	1.3	2.2	2.0	2.6	2.0
35	2.8	3.4	3.6	3.0	3.2
40	2.8	2.0	2.5	2.9	2.6
Mean	2.3	2.5	2.7	2.9	2.6
Outdoor storage, covered					
30	0.6	2.0	2.8	2.5	2.0
35	2.7	2.4	4.0	2.8	3.0
40	1.6	3.0	2.9	2.1	2.4
Mean	1.6	2.5	3.2	2.5	2.4
Indoor storage					
30	2.2	2.7	2.4	2.8	2.6
35	3.2	2.9	3.1	2.4	2.9
40	2.2	3.0	2.6	1.9	2.4
Mean	2.5	2.9	2.7	2.4	2.6
Means[1]	2.2a	2.6b	2.9b	2.6b	

[1]Means followed by the same letter do not differ significantly ($P > 0.05$).

however. Extraction should not be started until cone moisture drops below 50 percent. If drying conditions during storage are slower than in the current test, this may take longer than 8 days. The best extraction temperature was 35 °C, and higher temperatures should be used only with great care.

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A Case for Improving the Efficiency of Seed Extraction from Black Spruce (*Picea mariana* (Mill) B.S.P.) Cones

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Viable seed was obtained from cones of black spruce (Picea mariana *(Mill.) B.S.P.) through 16 extraction cycles. Although seed quality declined somewhat in later cycles, total yields were well above those commonly reported. Seed yields could be improved appreciably if more efficient extraction processes were developed.* Tree Planters' Notes 37(4):7–11; 1986.

The current expansion in black spruce (*Picea mariana* (Mill.) B.S.P.) reforestation programs, in both Canada and the United States, has greatly increased the demand for seed of this species. To meet this demand and to reduce the resultant high costs of cone procurement, efforts have focused on developing more efficient cone harvesting techniques and equipment *(10)*. Little attention has been given to the possibility of augmenting seed yields through refinements in extraction processes.

Average yields from large-scale extraction facilities range from 8 to 15 cleaned black spruce seed per cone *(4, 8)*. However, the seed potential—the maximum number of seeds a cone is capable of producing *(1)*—for this species is generally at least five times higher *(6, 7)*. Yields of more than 30 sound black spruce seeds per cone have been reported *(5)*. Undoubtedly the semi-serotinous nature of the cones makes efficient seed extraction more difficult.

During black spruce cone and seed studies we have invariably found seeds remaining in the cones following extraction *(8)*. In order to remove a large portion of the seeds from newly ripened cones, several extraction cycles have been necessary. This article outlines the effects of repeated soaking, drying, and tumbling cycles on seed yields and seed quality when small lot seed processing equipment is used. It also emphasizes the need to ensure that extraction and cleaning procedures for black spruce are as effective as possible, whether for processing small lots or for bulk quantities in large-scale extractories.

Materials and Methods

Three different September collections of newly ripened cones were used: a 1977 collection of 10 cones from each of 5 trees from a 40-year-old lowland stand east of Sault Ste. Marie, Ontario; a 1979 bulk collection from a 110-year-old upland stand near Thunder Bay, Ontario; and a 1980 bulk collection from a 90-year-old upland stand north of Thunder Bay. The cones from Sault Ste. Marie were stored in kraft paper bags at room temperature (20 °C) for 3 weeks before processing; those from Thunder Bay were stored at 0.5 °C for 5 months.

Two extraction methods were used. With method A, cones were soaked in 20 to 25 °C water for 30 minutes, drip-dried for 1 hour, heated in a drying oven for 22 hours at 50 °C, and then tumbled for 20 minutes. With method B, which was similar to that suggested by Safford *(8)*, cones were soaked in cold water for 4 hours, dried at room temperature for 20 hours, heated at 60 °C for 8 hours, and then tumbled for 20 minutes. In each case, cones were put through 16 repetitions (extraction cycles) of the particular extraction method(s) employed.

In the first experiment, the Sault Ste. Marie cones were processed separately for each tree by method A, while four 10-cone replicates from each of the Thunder Bay collections were processed by each method. Following the 16 extraction cycles, the Thunder Bay cones were dissected and the number of fully developed seeds *(1)* remaining was tallied. For each combination of cone collection and extraction method, germination tests were then conducted separately on all seeds recovered from each extraction cycle. Seeds were placed on saturated germination paper overlying bleached Kimpak in covered petri dishes and incubated under continuous low-level incandescent light at a constant 21 °C for 28 days *(2)*. Germination (radicle at least 2

millimeters long) was tallied daily.

In a second experiment conducted to obtain greater quantities of seed for a more thorough investigation of the effects of repeated soaking and tumbling cycles on seed quality, 10-liter lots of cones from each of the two Thunder Bay collections were cycled 16 times by method A. These seeds were subsequently dewinged and cleaned. Germination tests were then conducted on four 100-seed replicates per extraction cycle as described above, but at constant temperatures of 10, 21, and 32 °C *(2)*, and with a longer germination period (45 days) for the 10 °C tests.

In addition, after empty seeds were removed by flotation in absolute ethyl alcohol, four more 100-seed replicates from each extraction cycle were weighed. These were then sown on the surface of a 2:1 peat/vermiculite growing medium, placed in a heated greenhouse (18 to 23 °C) lighted 16 hours a day, and watered daily. After they developed primary needles, the seedlings were fertilized every second day with 50 parts per million nitrogen (20-20-20 NPK). Seedling heights and dry weights were determined after 20 weeks.

Germination characteristics were examined in terms of germination capacity (the proportion of full seed that germinated), uniformity of germination (time in days from the beginning of germination until 90 percent of the viable seed had germinated), and germination speed (time in days from sowing until 50 percent of the viable seed had germinated) for each replicate. Following transformation (arcsine) of germination capacity values, data were compared by analysis of variance techniques. Differences among treatment means were established with Tukey's multiple comparison test. Results are reported as mean values per treatment.

Table 1—*Average yields of fully developed seeds per cone following 16 extraction cycles*

Collection	Extraction method	Sample size (cones)	Total seed extracted	Total seed remaining in cone	Viable seed extracted	Percent viability
Sault Ste. Marie	A	50	80.0	ND	37.0	46
Thunder Bay, 1979	A	40	79.8	5.4	48.4	61
Thunder Bay, 1980	A	40	69.4	11.8	34.0	49
Thunder Bay, 1979	B	40	84.5	1.9	47.8	57
Thunder Bay, 1980	B	40	80.2	1.8	44.1	55

ND = not determined.

Results and Discussion

Mean seed yields after 16 extraction cycles ranged from 69 to 85 fully developed seeds per cone and from 34 to 48 viable seeds per cone (table 1), with an average of 2 to 12 fully developed seeds still remaining in each cone. As expected, yields per cycle decreased in later extractions (fig. 1). However, it is noteworthy that the second, third, and often the fourth cycles yielded more seeds than the first. This suggests that specific treatment may be required to enhance cone scale flexing and seed release.

Seed yields per cycle appeared to be affected by both cone storage and extraction methods (fig. 1). Cones stored at room temperature in paper bags (the Sault Ste. Marie collection) had dried and opened to some extent prior to extraction. They yielded greater quantities of seed during the first two cycles with method A than did those stored at 0.5 °C (the Thunder Bay collections). A significantly larger portion of the total seed yield was obtained by the first two or three cycles with extraction method B than with method A.

The proportion of extracted seed that was viable tended to be somewhat larger (by 5 to 15 percent) for the first three cycles, but thereafter exhibited no distinct trend. Average viability (all collections and extractions combined) was 60 percent for cycles 1 to 3 but only 48 percent for cy-

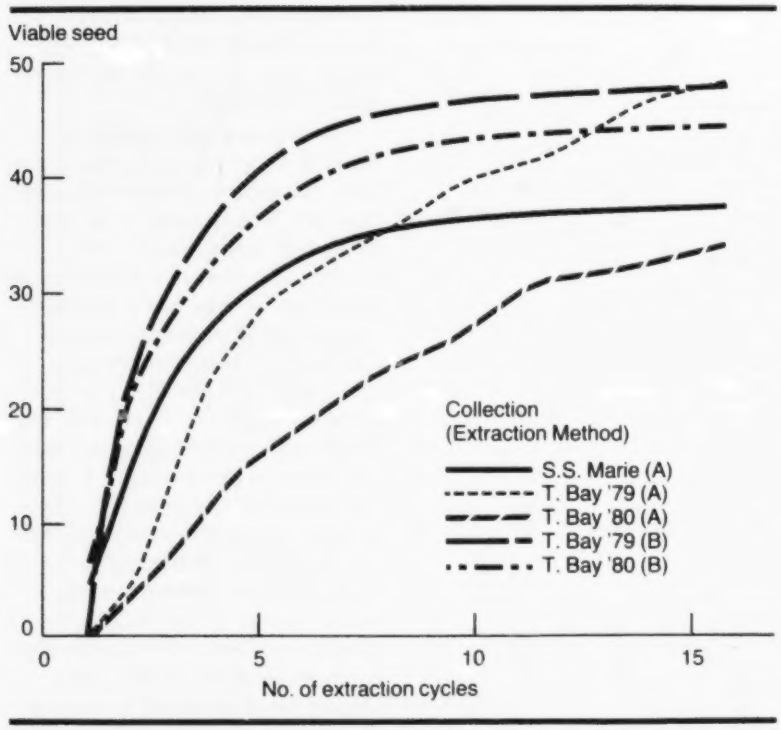

Figure 1—*Cumulative viable seed yields per cone by number of extraction cycles.*

cles 4 to 16. The drop in viability for later extractions reflected an increase in the proportion of empty seed, not a decrease in the viability of full seed. For almost all combinations of seed collection, extraction methods, and extraction cycle, over 90 percent of the full seed obtained was viable.

Although the number of viable seeds per cone can vary dramatically, these results suggest that healthy black spruce cones often contain considerably more viable seeds than are generally extracted. Comprehensive studies are needed to identify more efficient cone storage and extraction techniques to improve yields from large-scale facilities *(3)*. When small lots are processed by methods similar to those employed here, substantial quantities of viable seed ($\geq$ 2 seeds/cone) may be obtained through the sixth extraction cycle. Determinations of the number of viable seeds per cone based on two or three extraction cycles *(8)* can underestimate the true figure by as much as 50 percent.

To gain a better understanding of the effects of repeated extraction cycles on seed quality, we conducted germination tests at Fraser's *(2)* lower, optimum, and upper cardinal germination temperatures for black spruce. The germination capacity of the seeds was not significantly different for the first 6 to 7 extractions, regardless of germination temperature. Thereafter it decreased somewhat at 10 °C, but not at 21 or 32 °C. The speed and uniformity of germination tended to decline for later extractions, particularly at 10 °C (figs. 2 and 3). However, there was no significant difference in these two characteristics among seeds from the first 4 to 6 extractions at 10 °C, and from at least the first 5 to 6 extractions at 21 and 32 °C.

Direct relationships have often been reported between seed weight and germination or early growth characteristics. Skeates *(9)* found a direct correlation between black spruce seed weight and the size of first-year seedlings. In the present study the average weight of full seed decreased somewhat for later extractions, but significant reductions were not realized until the eleventh or twelfth cycle.

The greenhouse study was carried out to determine the effects of repeated soaking and tumbling on germination in a growing medium and on early

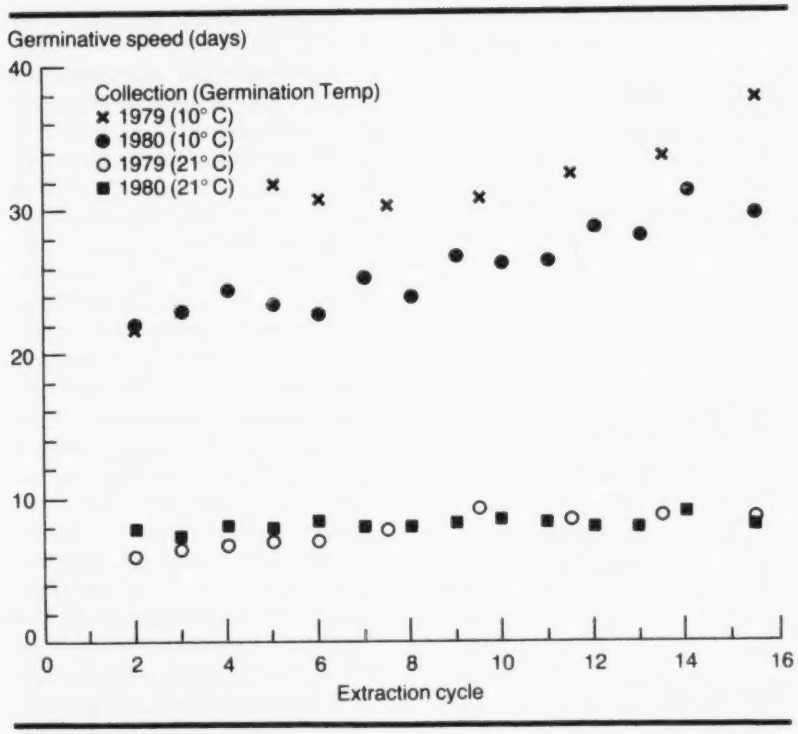

Figure 2—*Germinative speed at two temperatures for successive extractions from two collections. (Results at the 32 °C germination temperature were similar to those at 21 °C, and therefore are not presented.)*

growth. Seeds sown in the greenhouse exhibited germination characteristics similar to those exhibited by seeds incubated in cabinets at 21 °C; there were no significant differences in germination capacity among extractions, but the speed and uniformity of germination declined significantly by the eighth to twelfth cycle. Nevertheless, after 20 weeks, no significant differences were found between extraction cycles for survival, height, and dry weight of the resulting seedlings.

The gradual but consistent drop in the quality of seed from later extraction cycles may be of concern. While seed from later extraction cycles produces healthy and vigorous greenhouse seedlings, it may not perform as well in field conditions where germination temperatures are considerably lower (i.e., in outdoor nurseries or direct seeding programs), or following storage. The drop in seed quality following repeated extractions is likely to vary, depending on the extraction process and number of cycles employed. Hence, while reprocessing cones should be considered as an immediate step to improve seed yields, tests should be conducted to ensure that the additional seed procured is of sufficient quality to warrant this treatment.

Over the long term, refinements in cone storage and extraction techniques likely offer greater potential for increasing yields of high quality seed than does reprocessing with current technology.

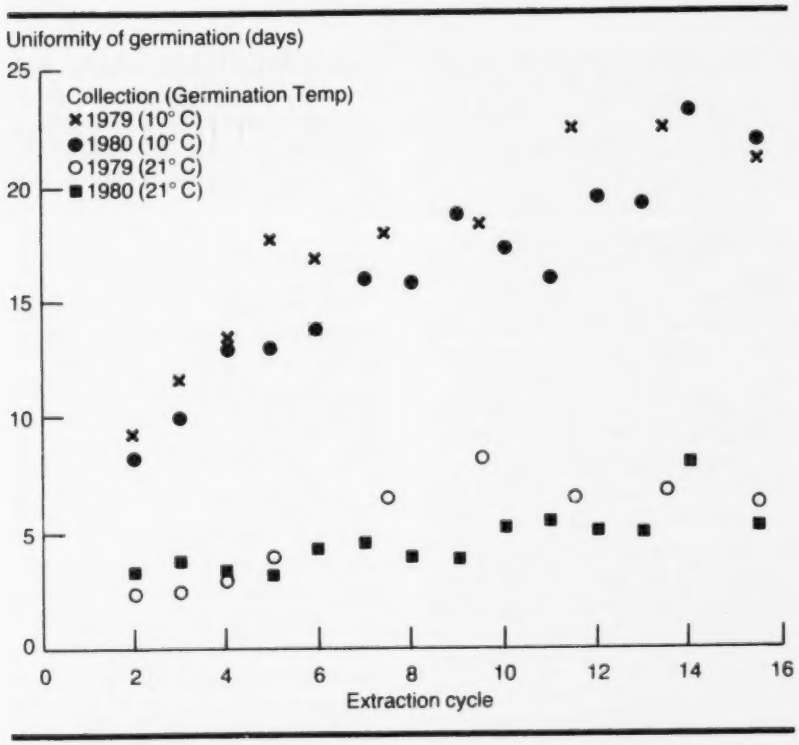

Figure 3—*Uniformity of germination at two temperatures for successive extractions from two collections. (Results at the 32 °C germination temperature were similar to those at 21 °C, and therefore are not presented.)*

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Homemade Potting Mixes for Container Planting in the Pacific Islands

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Locally available soil, sand, paper, and vegetative material were made up into potting mixes and compared with standard mixes of peat moss and vermiculite for suitability in growing Eucalyptus saligna *Sm. and* Casuarina equisetifolia *L. ex J.R. & G. Forst. Mixtures of one part each of grass clippings, soil, and calcareous sand produced good plantable stock of both species. Mixtures containing waste paper,* Leucaena leucocephala *(Lam.) de Wit leaves, and sand and soil without organic material were generally found to be failures for growing* Eucalyptus, *but* Casuarina *grew better in some of these media than in the commonly used peat moss/vermiculite.* Tree Planters' Notes 37(4):12–16; 1986.

Tube-container tree nurseries are becoming popular in some islands of Micronesia. Ideal materials for potting mix in the containers are peat moss and vermiculite. Unfortunately, the shipment of such bulky materials to these islands is prohibitively expensive. Thinking it possible to find some readily available substitute materials on these islands, we tried several soil and vegetative materials of Hawaii that essentially correspond to those in Micronesia. We tested these planting mixes by growing *Eucalyptus saligna* and *Casuarina equisetifolia* L. ex J.R. & G. Forst, both of which grow on some islands in Micronesia.

Potting mixes for tube-shaped containers must have suitable characteristics. Most importantly, they must remain soft and deformable so that the seedling can be removed from its container once it is grown. Tubes filled with sand or soil cannot be deformed by squeezing once the roots have filled the original voids in the medium, preventing the plants from being removed without serious breakage. The material must also provide rapid drainage, have a pH in the range suitable for the plants to be grown, and have a high cation exchange capacity. Ideally, the material should also be lightweight so that racks of containers and seedlings can be moved and handled easily.

Most tropical Pacific Islands have abundant coral ($CaCO_3$) sand and soils formed from calcareous rock. Many also have soils formed from basic igneous rock. The Mariana Islands, in particular, have extensive stands of *Leucaena leucocephala* (Lam.) de Wit, a weedy shrub or small tree that has lately become popular for fuelwood plantings. These islands also have scattered grass lawns, often near nursery sites, and abundant waste paper. Therefore, we selected the following materials for our trial potting mixes: sand, soil, leaves, grass clippings, and small bits of paper.

Methods

The materials selected for trial were beach sand, lowland soil, upland soil, *Leucaena* leaflets, lawn grass clippings, and confetti (to simulate finely cut waste paper). The beach sand, a mixture of shell and coral fragments, was essentially pure $CaCO_3$ with a pH of 8.4. It was washed to remove salt before use. The lowland soil was Waialua clay, an agricultural soil formed in place on an old coastline coral shelf with some igneous alluvium inclusions. The sample used had a pH of 6.2. The upland soil was Papaa clay, a reddish-brown oxisol formed on old basalt. The sample used had a pH of 4.4.

The sand and soils were fumigated with Dowfume (a restricted use fumigant requiring a licensed applicator) before mixing. The *Leucaena* leaflets, which are about 0.5 by 1 centimeter in size, were stripped from trees near the nursery and air dried. The grass clippings from a nearby Bermuda grass ('Sun Turf') lawn were used fresh. The confetti was circular bits of magazine paper about 0.5 centimeter in diameter. It had

clay coating and ink typical of waste paper of this type.

The constituents were mixed by hand using parts by volume, each part consisting of a loosely packed 500-milliliter beaker. The potting mixes were placed in tube-shaped polyethylene containers of the size and shape developed for use in Hawaii *(1)*. Two experiments were carried out at different seasons, each with the same control potting mix (2 parts peat moss, 1 part vermiculite), but with different treatments. Treatments were as follows:

Experiment 1
(cool season)

1. Peat moss (2 parts), vermiculite (1 part)—control
2. Leucaena leaves (2 parts), Waialua soil (1 part)
3. Leucaena leaves (2 parts), Papaa soil (1 part)
4. Leucaena leaves (2 parts), Waialua soil (1 part), beach sand (1 part)
5. Leucaena leaves (2 parts), Papaa soil (1 part), beach sand (1 part)
6. Confetti (2 parts), Waialua soil (1 part)

Experiment 2
(warm season)

7. Peat moss (2 parts), vermiculite (1 part)—control
8. Waialua soil (1 part), beach sand (1 part)
9. Papaa soil (1 part), beach sand (1 part)
10. Grass clippings (1 part), Waialua soil (1 part), beach sand (1 part)
11. Grass clippings (1 part), Papaa soil (1 part), beach sand (1 part)

We used 10 replications of each *Eucalyptus* treatment and five of each *Casuarina*. The tubes were completely randomized in one holding rack. The seedlings were grown on a greenhouse bench for 4 months.

During the growing period, seedlings were soaked once daily and fertilized twice weekly with 300 milliliters of a 1:1 mixture of Ortho 10-8-7 in water. The plants were started from a pinch of seed per tube and were thinned to one per tube when it became apparent that the seedling saved would survive. Germination tests were made of 30 seeds of each species on gravel-covered media of the same mixtures in the tubes.

Survival counts and height growth measurements were made monthly. At termination after 4 months' growth, seedlings were photographed, then removed from their containers using—to the extent possible—uniform hand squeezing and pulling procedures. The ease of removal from the tube, the retention of a tube shape by the root mass upon removal, and the compactness of the root mass were comparatively rated for acceptability for planting.

Then, the medium was washed from the roots, and the roots and tops of the plants were measured and weighed. Measurements consisted of total leaf area, total root area, and ovendry weights of tops and roots. The presence and amount of root nodules on *Casuarina* were also noted.

Results and Discussion

Treatments that included *Leucaena* leaves exhibited poor germination after only 3 weeks, more apparently among the *Eucalyptus* than the *Casuarina*. Germination tests were then started in sand alone and in the other media from experiment 1, with sand substituting for the control. In these tests, 30 seeds of each species were placed on each medium. Counts were made after 10, 20, and 30 days (table 1). These separate germination tests were made because a pinch of seed, rather than a known number, had been placed in the tubes.

In the second experiment, germination was satisfactory in tubes. Independent germination tests were therefore not made. However, of the five treatments

Table 1—*Germination percentage of* Eucalyptus saligna *and* Casuarina equisetifolia *sown on sand and other media*

		Germination percentage after sowing					
		10 days		20 days		30 days	
	Treatment	Euc.	Cas.	Euc.	Cas.	Euc.	Cas.
1.	Sand	37	27	43	33	43	33
2.	Leucaena + Waialua	0	7	0	13	0	13
3.	Leucaena + Papaa	0	3	0	3	0	3
4.	Leucaena + Waialua	3	7	3	7	3	7
5.	Leucaena + Papaa	3	10	3	20	3	23
6.	Paper + Waialua	23	17	23	33	23	33

Euc. = *Eucalyptus saligna*; Cas. = *Casuarina equisetifolia*.

in the second test, the two *Eucalyptus* treatments with grass clippings required pricking in of seedlings from other tubes to 4 tubes out of 10 in each treatment in order to obtain 10 replications.

It was apparent that nondecomposed vegetative material reduced and retarded germination. *Leucaena* and grass retarded *Eucalyptus; Leucaena* alone retarded both *Casuarina* and *Eucalyptus*. The effect of *Leucaena* is believed to be caused by phenolic substances formed in the leaves in the early stages of decomposition. Kuo et al. *(2)* found that extracts of air-dried *Leucaena* leaves inhibited or suppressed radicle growth of several species. In our study, *Eucalyptus* was affected to a greater degree than *Casuarina*. Had we been aware initially of the problem with *Leucaena*, we would have composted the leaves to overcome the problem.

After growing for 4 months, the seedlings were removed from their containers. The tube was first squeezed to deform the root mass and free it from the container walls, then the plant and root mass were pulled out. We tried to do this in as similar a manner as possible for each seedling. The ease of removal and the retention of root mass form after removal were judged on the basis of acceptability for planting and probability of seedling survival. The percentage that was rated acceptable varied for the different treatments (table 2).

The pH of the peat moss–vermiculite mix was quite different between the two experiments (table 2). The reason is unknown because we did not check the pH of the ingredients of the second batch before combining them. Although the first, more-acid peat moss-vermiculite mix was suitable for both species, the second, less-acid batch was not at all suitable for growing *Casuarina*.

All five plants in this second control treatment nodulated well but were significantly lower in dry weight than the plants in the other treatments. The peat moss–vermiculite mix also produced lightweight *Casuarina* plants in the first (cool season) experiment, suggesting that this much-used mix is not well-suited for the species. Both species grew much larger in the second experiment, which was carried out in late summer and fall during very favorable warm weather.

Leucaena leaflets greatly raised the pH of the soils and sand–soil mixes to which they were added. Their addition had an ameliorative effect apparently about equal to that of the pure calcium carbonate sand. Both *Eucalyptus* and *Casuarina* had germinated satisfactorily in this sand.

Poor survival of three of the four *Eucalyptus* treatments containing *Leucaena* leaflets may have influenced statistical comparisons with the control. The plant roots had not grown sufficiently in these mixtures of

Table 2—*Survival, condition, and growth of* Eucalyptus saligna *and* Casuarina equisetifolia *seedlings after 4 months in the potting mixes tested*[1]

Treatment	Initial pH	% Survival	% Acceptable	Height at 4 months (cm)	Leaf area (cm^2)	Dry weight (g)
Eucalyptus saligna						
Experiment 1						
1. Peat + vermiculite	5.4	100	100	13.0 a	41.7 a	0.57 a
2. Leucaena + Waialua	6.3	30	33	8.4 a	34.6 a	.44 ab
3. Leucaena + Papaa	6.0	20	50	8.9 ab	46.8 a	.54 ab
4. Leucaena + Waialua + sand	7.3	30	67	10.6 a	46.6 a	.60 a
5. Leucaena + Papaa + sand	7.2	90	78	12.6 a	58.0 a	.69 a
6. Paper + Waialua	6.5	100	0	3.2 b	1.3 b	.05 b
Experiment 2						
7. Peat + vermiculite	6.3	100	100	25.7 x	95.1 x	1.82 x
8. Sand + Waialua	6.5	100	60	20.2 x	62.7 x	1.42 x
9. Sand + Papaa	6.2	100	100	24.4 x	73.4 x	1.68 x
10. Grass + Waialua + sand	6.9	100	90	26.4 x	95.2 x	1.81 x
11. Grass + Papaa + sand	6.5	100	80	19.8 x	76.0 x	1.39 x
Casuarina equisetifolia						
Experiment 1						
1. Peat + vermiculite	5.4	100	100	14.2 a	8.4 a	0.23 a
2. Leucaena + Waialua	6.3	60	67	9.7 a	7.1 a	.20 a
3. Leucaena + Papaa	6.0	80	50	15.6 a	13.7 a	.44 a
4. Leucaena + Waialua + sand	7.3	100	100	18.8 a	15.1 a	.41 a
5. Leucaena + Papaa + sand	7.2	60	100	16.9 a	14.8 a	.37 a
6. Paper + Waialua	6.5	0	—	—	—	—
Experiment 2						
7. Peat + vermiculite	6.3	100	60	19.1 x	15.6 x	.36 x
8. Sand + Waialua	6.5	100	80	30.0 y	42.1 y	1.02 y
9. Sand + Papaa	6.2	100	80	27.7 xy	37.9 xy	1.02 y
10. Grass + Waialua + sand	6.9	100	100	33.5 y	54.3 y	1.39 y
11. Grass + Papaa + sand	6.5	100	100	31.0 y	49.7 y	1.19 y

[1]Means followed by the same letter in the same species and experiment do not differ significantly at the 5 percent level.

leaves and soil to hold the root mass together, so even the survivors were judged unacceptable for planting. The addition of sand improved the *Leucaena*-soil mixes for use with *Eucalyptus*, but the plants were hard to remove from the tubes, particularly those with the stickier Waialua soil. Only 3 of 10 plants survived in the *Leucaena*-Waialua-sand mixture, while 9 of 10 did in the mixture with Papaa soil.

As mentioned, germination was reduced by the presence of *Leucaena* leaves and to a lesser extent by grass. It was possible to lift extra seedlings from those tubes containing grass treatments and transplant them into tubes where none germinated, after which they grew well. In *Eucalyptus* and *Casuarina* treatments with poor survival, the losses

occurred after germination and resembled damping off. We believe that the poor germination and subsequent mortality could have been avoided had we used decomposed, rather than air-dried, leaves because *Leucaena* leaves are often used in Hawaii for compost without problems of phytotoxicity.

The mix of small bits of paper and Waialua soil was a complete failure with both species. The paper impeded drainage. The medium was always completely saturated, and root growth could not occur except at the surface, where oxygen was available. It is possible that either the ink or the coating on the paper was toxic, but it appeared obvious to us that poor drainage was the primary cause of poor growth because germination of the *Eucalyptus* was unaffected. The roots were too small to hold the mix together when pulled from the tubes.

In the first experiment, the only acceptable *Eucalyptus* treatment other than the control was number 5, *Leucaena* + Papaa + sand, and even that treatment had two failures during removal of plants from the tubes when the medium fell apart.

The results were somewhat better with *Casuarina* (table 2). Both *Leucaena* + soil + sand treatments produced acceptable plants with plantable root systems, although poor survival of treatment 5 indicates that treatment 4 might be the better choice of the two. Curiously, the roots of these two treatments grew in the center of the tubes rather than along the tube walls as they normally do in peat moss + vermiculite.

In the second experiment, all four trial mixes produced acceptable growth in both species (table 2). For *Casuarina*, all trial mixes were much better than the peat moss-vermiculite control, with the grass-soil-sand mixes promoting significantly better height, leaf area, and weight. The sand-soil mixes were very hard and difficult to deform once the roots had filled the tubes, causing plants to break on removal. This was very pronounced with *Eucalyptus* in the sand-Waialua soil mix, but it was possible to obtain complete plants from the sand-Papaa soil mix with considerable extra effort. Because of this difficulty of removal, we consider the grass-soil-sand mixes to be the only ones really acceptable among those tried. Nodulation of *Casuarina*, present to some extent in all treatments, was equally complete in the control and the two grass-soil-sand treatments.

Conclusions

An apparently acceptable potting mix can be made of local materials available on most of the Pacific Islands. Based on the results of this study, we suggest composting any fresh organic material to allow at least partial decomposition before use. Fresh or air-dried *Leucaena* leaves should be avoided. In fact, we suggest avoiding the fresh leaves of any plant that has a sparse or absent understory, which indicates possible allelopathy, a survival mechanism common to many plants.

Mixtures of sand, soil, and grass clippings were acceptable as potting mixes for *Eucalyptus saligna*, and were actually preferable to the peat moss-vermiculite mix commonly used in nurseries in Hawaii for *Casuarina*. Survival and growth in the sand, soil, and grass mix would likely have been better if composted grass had been used.

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Effect of Fall Sowing and Solar Heating of Soil on Two Conifer Seedling Diseases

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Solar heating did not reduce Macrophomina phaseolina *at any soil depth and eliminated* Fusarium oxysporum *f. sp.* pini *in the top 10 centimeters only. Fall sowing of* Abies concolor *and* Pseudotsuga menziesii *did not reduce disease, but did result in taller seedlings than did spring sowing.* Tree Planters' Notes 37(4):17-20; 1986.

Conifer seedlings are susceptible to a number of common soilborne fungi, including *Rhizoctonia solani* Kuehn, *Pythium* spp., *Phytophthora* spp., *Fusarium oxysporum* (Schlecht.), and *Macrophomina phaseolina* (Tassi) G. Goid. *(10)*. These pathogens are controlled primarily by fumigation with a methyl bromide-chloropicrin mixture applied in the late summer or fall when the soils are warm.

A cover crop, usually vetch (*Vicia sativa* L.), is sown in the fall to control winter soil erosion.

In spring, as early as weather permits, the cover crop is turned under, and the soil is prepared for sowing. Sowing is usually done in April or May. Recent research with *Pinus lambertiana* Dougl. has shown that early sowing (before March 15) results in larger seedlings and reduced losses from disease *(3)*.

Solar heating (solarization) of soil for control of soilborne pathogens is an accepted disease control practice in agricultural regions with high summer temperatures *(4)* and has been effective in reducing damping-off in a forest tree nursery *(2)*. The purpose of this study was to determine the effectiveness of solar heating for controlling soilborne pathogens of conifer seedlings in a California forest tree nursery and to evaluate the effect of fall sowing on seedling growth and survival. A preliminary report has been published *(6)*.

Material and Methods

Two nursery experiments were conducted at the Institute of Forest Genetics (Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture), Placerville, CA. The nursery is situated on a broad ridge below the snow line in the American River watershed of the western Sierra Nevada (38°45' N. 120°44' W). Elevation is 838 meters, and the soil is Aiken clay loam *(11)*.

Experiment 1. In 1981, inocula of *F. oxysporum* (originally isolated from *P. lambertiana* and grown on autoclaved, chopped alfalfa hay) and inoculum of *M. phaseolina* (recovered from soil) were rototilled into the top 15 centimeters of soil. The soil was brought to field capacity, and then covered with 0.1-millimeter-thick clear polyethylene from July 1 to September 9.

The sampling design consisted of four solarized and four nonsolarized areas each measuring 1.5 by 7.5 meters arranged in randomized blocks. Nylon mesh bags containing 25 grams of soil infested with *F. oxysporum* f. sp. *pini* and *M. phaseolina* were buried along with thermocouples at depths of 0, 2.5, 10, 20, 30, and 40 centimeters.

The nylon bags were retrieved at the end of the solarization period, and the propagule levels were determined according to the methods of Komada *(5)* and McCain and Smith *(7)*.

For fall sowing, seeds of rape (*Brassica napus* L.), annual ryegrass (*Lolium multiflorum* Lam.), and common vetch (*Vicia sativa* L.) were sown on November 3 in rows located between 1.5-m rows of seeds of *P. lambertiana* spaced 7.5 cm apart.

Eighteen rows of *P. lambertiana* were sown for a total of 360

seeds per cover crop subplot in the solarized and nonsolarized plots. Nonplanted areas were reserved for spring sowing. Cover crops were killed by spraying with glyphosate on March 24, 1982, prior to emergence of the conifer seedlings. *P. lambertiana* seeds for the spring sowing on April 22, 1982, had been soaked for 36 hours in aerated water at 25 °C, drained, and placed in polyethylene bags held at 1 °C for 90 days.

Experiment 2. A similar solarization trial was conducted in 1982. The solarized and nonsolarized subplots were smaller than before (1.5 by 3.7 meters), and thermocouples were buried with mesh bags of infested soil at depths of 10, 20, and 30 centimeters. The 0.05-millimeter-thick polyethylene solarization covers were placed on June 17 and removed on August 22, 1982. Vetch seeds were distributed throughout the fall planting subplots and 3 species of conifers—*Pinus lambertiana, Pseudotsuga menziesii* (Mirb.) Franco, and *Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.—were sown on October 4, 1982. The vetch was removed by hand on April 4, 1982, because some conifer seedlings had emerged and application of herbicide might have damaged them. Spring sowing was done on May 4, 1982.

A mechanical pyranograph (Weathermeasure R401) recorded solar radiation in both the 1981 and 1982 trials.

Isolations from dead or dying conifer seedlings were grown on water agar plus 1- to 2-millimeter bits of propylene oxide-sterilized pea straw.

Height measurements were made in October, after the seedlings ceased apical growth.

Results

In 1981 the weather during the 55-day solarization treatment was clear except for partly cloudy days on July 22 and August 18. The maximum solar radiation on July 15 was 1.05 calories per square centimeter per minute and on September 9 it was 0.855. The relative humidity averaged 26 percent, and the maximum and minimum air temperatures were 34.4 °C and 19.4 °C. Soil temperatures beneath the polyethylene tarps were maximum between July 28 and August 14.

In 1981 the rototilled soil contained an average of 8.4 propagules per gram of *M. phaseolina* before solarization. After solarization, the average was 5.1 propagules per gram of *M. phaseolina* in the solarized plots and 30 propagules per gram in the nonsolarized plots. After rototilling and prior to solarization the soil contained 1.9×10^3 propagules of *F. oxysporum* f. sp. *pini*. After solarization the level of *F. oxysporum* had dropped to 8.5 propagules per gram in the solarized soil and 1.2×10^3 in the nonsolarized plots.

There were 31 cloudy days during the 66-day solarization period in 1982 with rain on several of those days. The maximum solar radiation, 1.07 calories per square centimeter per minute, was recorded on July 4 and the lowest value, 0.885, was recorded on August 22. During the solarization period the average relative humidity was 38 percent, the maximum air temperature of 36.7 °C occurred on July 13 and the minimum air temperature of 8.3 °C occurred on July 4. Solarization was interrupted for 10 days beginning on July 29 because of wind damage to the polyethylene sheeting. The 0.05-millimeter-thick polyethylene was not strong enough for the wind conditions that occurred during the summer of 1982.

In 1982 the rototilled soil contained an average of 15 propagules per gram of *M. phaseolina* and 1.1×10^3 propagules per gram of *F. oxysporum*. After solarization, the average was 8.2 propagules per gram of *M. phaseolina* in the solarized plots and 14 propagules per gram in the nonsolarized plots, whereas 5.4 propagules per gram of *F. oxysporum* were detected in samples taken from

Table 1—*Survival of* Fusarium oxysporum *and* Macrophomina phaseolina *in solarized (S) and nonsolarized (N) soil*

Soil depth (cm)	Max. soil temp.(°C)			Propagules/g of soil							
				Fusarium (× 10^4)				Macrophomina			
	1981		1982	1981		1982		1981		1982	
	N	S	S	S	N	S	N	S	N	S	N
0	47	62	—	0	0.10	—	—	102	12	—	—
2.5	47	59	—	0	19[a]	—	—	241	1050	—	—
10	37	48	50	0.01	13	0.60[b]	81	718	882	16	17
20	30	38	40	10	11	65	72	1490	945	23	12
30	28	36	37	32[a]	11	55	63	1210	815	20	22
40	27	36	—	31[a]	25[a]	—	—	692	1320	—	—

[a]Significantly different from the surface-solarized soil. ($P = 0.05$).
[b]Significantly different from the deeper solarized and from the nonsolarized soil ($P = 0.05$).

the top 10 centimeters of solarized soil and an average of 4.9×10^2 from the nonsolarized plots.

The magnitude and duration of the temperatures achieved in both 1981 and 1982 were sufficient to achieve control of *F. oxysporum* in the surface soil but not at greater depths. *M. phaseolina* was not controlled at any depth although there may have been some reduction in propagule survival in the bare surface soil (table 1).

Rodents ate most of the *P. lambertiana* seeds in the 1981 fall and spring sowings, and no significant survival or growth measurements were possible. The three cover crops made satisfactory growth in the fall and would have provided erosion control on sloping land. Vetch was chosen for the 1982 trial because it is commonly used for erosion control and appeared to cause minimal disruption of the conifer seeds.

Rodents again ate the fall-planted *P. lambertiana* seeds in 1982 and mortality from disease could not be accurately assessed. There was no significant difference in survival between the fall and spring sowings of *A. concolor* and *P. menziesii*. There were differences in the populations of pathogens involved in mortality. Diseased seedlings from solarized plots yielded *M. phaseolina*, whereas seedlings from nonsolarized plots primarily yielded *F. oxysporum*.

No benefit in seedling survival from the solarization treatment was detected in either 1981 or 1982.

Seedlings of *A. concolor* and *P. menziesii* that developed from fall-sown seeds were larger than those from the spring sowing. Seedlings from fall-sown *P. lambertiana* were also larger but this difference was not statistically significant in this trial (table 2).

Discussion

Fall and winter sowings most closely simulate natural environmental conditions for seed germination, seedling emergence, and early growth *(3)*. The major advantage of fall sowing is the ease of soil preparation and planting during favorable weather. Fewer soil preparation operations are necessary with fall planting, and it is unnecessary to cold treat the seed because this occurs in the field.

However, possible rodent damage is a major disadvantage of fall sowing. In this study the nursery beds were adjacent to

Table 2—*Survival and growth of conifer seedlings in fall and spring sowings in solarized (S) and nonsolarized (N) soil*

	Survival (%)		Height (mm)	
	S	N	S	N
Abies concolor				
Fall	62.5	52.1	62*	84*
Spring	43.6	51.1	42	43
Pinus lambertiana				
Fall[1]	3.4	4.1	165	117
Spring	87.5	88.0	132	117
Pseudotsuga menziesii				
Fall	56.2	70.4	115*	145*
Spring	66.1	72.0	88	113

*Significantly different (P = 0.05).
[1]Poor survival because of rodents.

uncultivated areas that harbored the rodents. This situation should be considerably less of a problem in large nurseries, and poisons could be applied to the seeds to eliminate the rodents.

The failure of fall sowing in these trials to reduce mortality due to disease was probably related to the high inoculum levels of *F. oxysporum* and *M. phaseolina* in the soil. Fall sowing into fumigated soil should result in the production of superior healthy seedlings.

It is not surprising that *M. phaseolina* was not controlled by solar heating of soil, for sclerotia of the fungus are resistant to prolonged high temperatures *(1)*. *M. phaseolina* was not eliminated by soil solarization in trials conducted in Arizona *(9)*.

It may be possible to control conifer seedling diseases through solar heating of soil where *M. phaseolina* is absent or in very low numbers. The monitoring of nursery soil for sclerotia of the fungus would be a simple matter because improved assay methods are available *(8)*.

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Propagation of Red Alder (*Alnus rubra* Bong.) by Mound Layering

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Mound layering using 2-year-old nursery-grown seedlings of red alder (Alnus rubra *Bong.) produced about seven rooted sprouts per stump. Most survived separation from the parent plants, and all had strong, upright growth habits.* Tree Planters' Notes 37(4):21–23; 1986.

Red alder (*Alnus rubra* Bong.) is the most common hardwood in the Pacific Northwest. It is anticipated that the importance of this species for wood products or as a nitrogen fixer may reach a point where genetic improvement will be desirable. Because considerable variation exists in red alder *(3)*, the genetic improvement potential seems high. Such genetic improvement could achieve immediate gains if the best trees could be cloned to produce numerous individuals for field planting *(2,5)*.

Little information has been reported on the vegetative propagation of red alder. However, excellent rooting results with greenwood cuttings taken from 1- to 3-year-old seedlings have been achieved *(7)*. Another method of vegetative propagation that we believe may show promise is mound layering. In mound layering, the stems of young plants are cut back to the ground and soil is heaped around the subsequent sprouts *(6)*. It is commonly used to produce apple and quince root stocks *(1)*.

Several sources of information led us to think that mound layering would work. For example, red alder planted in Hawaii, where the humidity is very high, showed a tendency to produce adventitious roots *(4)*. In addition, from one of our own studies we found that the buried branches on some 2-year-old alder that were planted too deep had produced roots. We also knew from our frequent slashing of small alder reproduction out of research plots that each cut stem sprouted back vigorously each year with multiple stems.

We had good evidence, therefore, to believe that red alder could be vegetatively reproduced by mound layering. This technique can be carried out on a production basis in a nursery, without the use of greenhouses or special rooting beds. It has the potential to produce large plants in one growing season.

Methods

Red alder seed was sown in small outside nursery beds. After 2 years the plants had reached 2 meters in height and were 40 to 60 centimeters apart. The following January seven of these plants were cut back to 7 to 10 centimeters above ground. Many sprouts originated from each of the stumps and on June 1 when the sprouts were 20 to 25 centimeters tall the base of all the sprouts and the stumps were covered with 7 to 10 centimeters or more of nursery soil. The tips of the sprouts were never covered and none were pruned out to avoid crowding. Irrigation was provided during the summer on a regular basis. In March of the following year these 1-year-old sprouts were counted, measured for height, and examined for rooting.

Results

There were 71 exposed sprouts growing from the seven stumps at the start of the study. Of the 47 sprouts that survived the summer, all developed roots. The number of sprouts per stump ranged from 3 to 9, with an average of 6.7. Sprout heights ranged from 0.39 meters to 2.63 meters, with an average of 1.11 meters. The more sprouts in a clump, the greater the range in height.

The number of roots on each sprout varied considerably (figs. 1 and 2). Large sprouts lower on the same stump had more and larger roots, whereas the dominant sprout, which originated near the top of the stump, had the fewest roots. These uppermost sprouts were covered with less soil, so that they may have been too dry for good rooting. The sprouts were very limber at the time of mounding and some were forced down by the weight

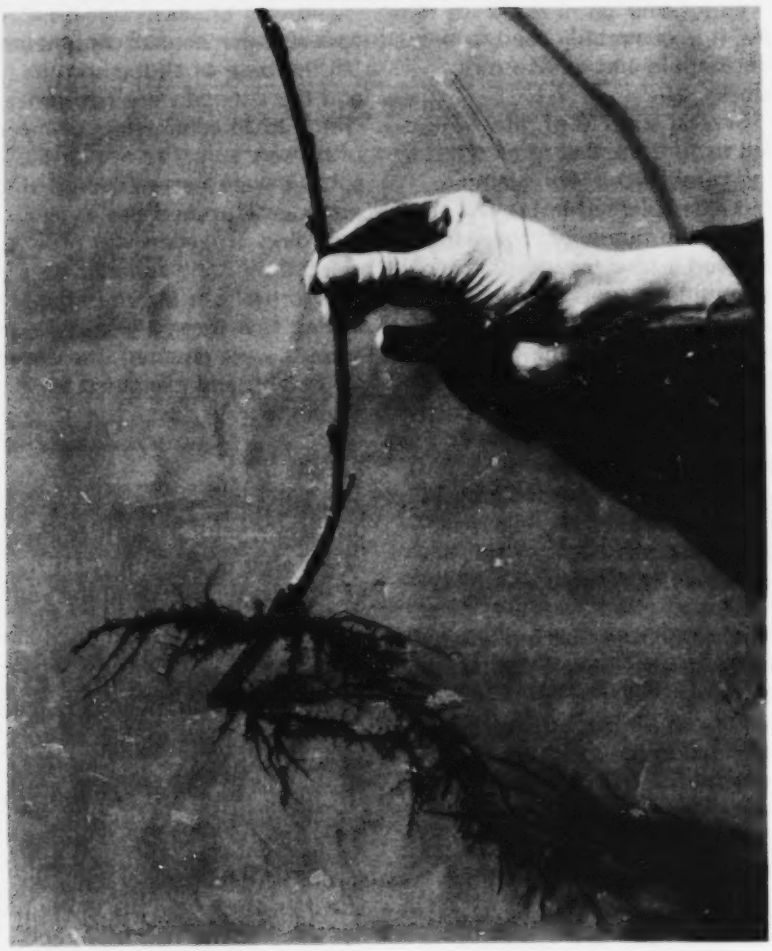

Figure 1—*A small red alder sprout with adequate rooting, held in its natural position.*

of the soil. These sprouts were covered over a greater length than the others, in one case a full 12 inches, and rooted well along the entire buried length.

Each clump of sprouts was dug up and examined. Most of the sprouts were well rooted and had well-developed mycorrhizae. Red alder is a nitrogen-fixing species and the roots on the new sprouts were also well nodulated. The rooted sprouts were easily cut from the parent stump and transplanted. If the stumps are left in place for annual production it may be more difficult to separate the rooted plants because of the heaped soil. However, heaping the soil on the sprouts so that they lay out and away from the parent stump may promote easier separation.

The transplanted rooted sprouts were grown for 1 year in a nursery bed and were regularly irrigated. With the exception of a few poorly rooted sprouts, all survived the growing season. Most were vigorous, and all were strongly orthotropic. Though not tested further, these rooted sprouts appeared to have excellent potential for continued growth and development.

Conclusions

Most of the sprouts were well rooted and vigorous and showed an upright growth habit. We therefore concluded that mound layering is an excellent method of reproducing selected clones of red alder. Established stumps spaced 2 feet apart should produce 5 to 8 sprouts per year at least 1 meter tall.

Figure 2—*One of the largest and best rooted red alder sprouts.*

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Comparison of Survival Enhancement Techniques for Outplanting on a Harsh Site in the Western Oregon Cascades[1]

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Bareroot seedlings of Douglas-fir (Pseudotsuga menziesii *(Mirb.) Franco) survived and grew better than container-grown stock planted on a droughty site in the western Cascade Mountains. Shading improved survival and growth, but field application of a solution of* Pisolithus tinctorius *basidiospores to the roots did not.* Tree Planters' Notes 37(4):24–28; 1986.

Droughty sites on the west slope of the Oregon Cascade Range can be difficult to reforest after clearcutting, and intensified reforestation efforts are often needed. The use of container-grown seedlings, shading, or mycorrhizal inoculations may help regenerate these sites.

The performance of container-grown and bareroot seedling stock of Douglas-fir *Pseudotsuga menziesii* (Mirb.) Franco has been compared in field tests in Oregon *(5,6,9,21)*. These studies suggest that container-grown stock survives better than bareroot stock on south-facing slopes or sites with rocky or shallow soil. Bareroot stock, which is generally larger, competes better than container stock with brush on wet sites or slopes with northern aspects.

Other studies have shown that shade can increase survival on droughty sites with southern exposures by reducing water stress and surface soil temperatures that may damage the seedling's cambium near the root collar *(1,7,8,11,17,22)*.

The ectomycorrhizal fungus *Pisolithus tinctorius* (Pers.) Coker & Couch has demonstrated a tolerance to xeric, high-temperature sites with low fertility *(12,13,16,23)*. Research to date has primarily involved inoculation of nursery seedlings *(3,10,14,15,25)*. Applying basidiospores of mycorrhizal fungi to seedling roots in the field immediately before outplanting has logistic advantages, including ease of application and low costs.

The purpose of this experiment was to examine reforestation improvement methods for harsh sites by comparing survival and height growth of Douglas-fir seedlings after the first and third growing seasons. The following methods were compared: bareroot versus container-grown stock; shaded versus nonshaded seedlings; application of *Pisolithus tinctorius* basidiospores to seedling roots versus no application.

Methods and Materials

The experiment was installed in a clearcut on the west slope of the Cascade Mountains, 50 kilometers east of Sweet Home, Oregon. The site has a south-southwest aspect and an elevation of 1000 meters. It was logged in 1974 and broadcast-burned in 1976. Existing brush consisted of scattered, short (1.5-meter) clumps of rhododendron, salal, and vine maple. Adjacent forest communities are characterized by the *Tsuga heterophylla/ Castanopsis chrysophylla* association *(4)*. An intense broadcast burn; deer browsing; south-southwest exposure; and the shallow, skeletal soils had contributed to past reforestation failures.

We used a split block experimental design with six blocks. Each block of 400 seedlings had 100 trees in each of four treatments: (1) control, (2) shade, (3) spore application, and (4) shade and spore application. Within each treatment, 50 bareroot and 50 container-grown seedlings were installed in randomly arranged rows of 10 seedlings each. The data were analyzed

[1]This study was conducted in cooperation with the U.S. Department of Agriculture, Forest Service, Willamette National Forest, Sweet Home Ranger District, and the Pacific Northwest Forest and Range Experiment Station, Forest Sciences Laboratory, Corvallis, OR.

using multivariate analysis of variance *(18, 20)*. Tukey's honestly significant difference test for multiple comparisons *(19, 24)* was used to compare treatment means.

Seed used for both the bareroot and container-grown seedlings was collected from the appropriate seed zone. Container trees were 1–0 stock grown in Ray Leach pine cells (65 cubic centimeters) at Beaver Creek Nursery near Philomath, Oregon, and were mostly nonmycorrhizal when spores were applied. The bareroot seedlings were 2–0 stock grown at Wind River Nursery near Carson, Washington, and had some mycorrhizae.

The basidiospores were provided by Dr. James Trappe of the Forestry Sciences Laboratory in Corvallis, Oregon. Sporocarps had been collected the previous fall, then dried and refrigerated. Spores were extracted March 1980 and stratified by soaking in cold water for a week. Bareroot seedlings were dipped in a spore solution slurry at the planting site and container seedlings were watered with the spore solution the day before. Spore concentration and water usage were such that the roots of each seedling, of both stock types, received about 1 milligram of spores.

Seedlings were hand planted in early May 1980 at a 3-foot spacing. Shading was provided with slitted, waxed cardboard rectangles (25 by 50 centimeters) slipped on and stapled to wooden lath that was staked on the southwest side of appropriate trees. Existing brush was cut by hand to eliminate natural shade. Deer browse was reduced with big-game repellent. Survival and leader growth were measured in October of 1980 and 1982.

Results and Discussion

There were no significant interactions between treatments and stock types in either the first or third year survival or leader growth analyses, so interpretation of the results was straightforward.

Bareroot stock survived and grew in height significantly ($P = 0.01$) better than container-grown stock the first year. After 3 years, survival still differed significantly ($P = 0.05$), but height growth did not (fig. 1).

Shaded seedlings survived significantly better after both the first ($P = 0.01$) and third ($P = 0.05$) growing seasons than did unshaded seedlings, regardless of spore application. Spore application did not significantly affect survival. Shaded-only seedlings had grown significantly ($P = 0.05$) more than spore-application-only seedlings after the first year. After 3 years no significant growth differences remained among the treatments (fig. 2).

Stereo-microscope (3 to 5 times magnification) examination of first- and third-year roots of selected seedlings showed no development of *Pisolithus tinctorius* mycorrhizae.

The poor performance of container-grown stock in our study conflicts with recent reports of better survival of container-grown seedlings on south-facing, droughty sites *(6,9)*. Our container stock may have sustained root damage during a hard freeze the previous winter, as suggested by some early summer mortality. The smaller stems of the container-grown seedlings may also have been more easily damaged by rough handling during planting.

In spite of their small size, surviving container seedlings had as much leader growth as bareroot seedlings by the third year. Also, survival of bareroot stock declined by 26 percent between the first and third year, whereas container-grown seedling survival declined only 4 percent during the same period. Clearly,

many factors influence the relative long-term benefits of using these stock types.

Our shading results concur with the literature, but survival differences were small (less than 20 percent). The first growing season was moist and cool, which possibly reduced the benefits of shade during a more typical growing season. As of 1980, the cost for materials and installation of artificial shade approached $180.00 per acre. Closer initial seedling spacing would have been more cost-effective on this site, given the first growing season's weather. Shade is justified when other treatments cannot reasonably ensure acceptable stocking levels.

Although planting nursery-inoculated mycorrhizal seedlings may enhance survival, the application of *Pisolithus tinctorius* spores to a seedling's roots immediately preceding outplanting appears to be ineffective. Alvarez and Trappe *(2)* hypothesized that dusting roots with spores before outplanting was ineffective or harmful because a dense coating of hydrophobic spores would inhibit water uptake by the seedlings. This was not the case in our study, because spores were applied in a liquid suspension; however, the lack of *Pisolithus tinctorius* mycorrhizae formation argues against the effectiveness of this technique.

Project costs for field application of basidiospores to seedling

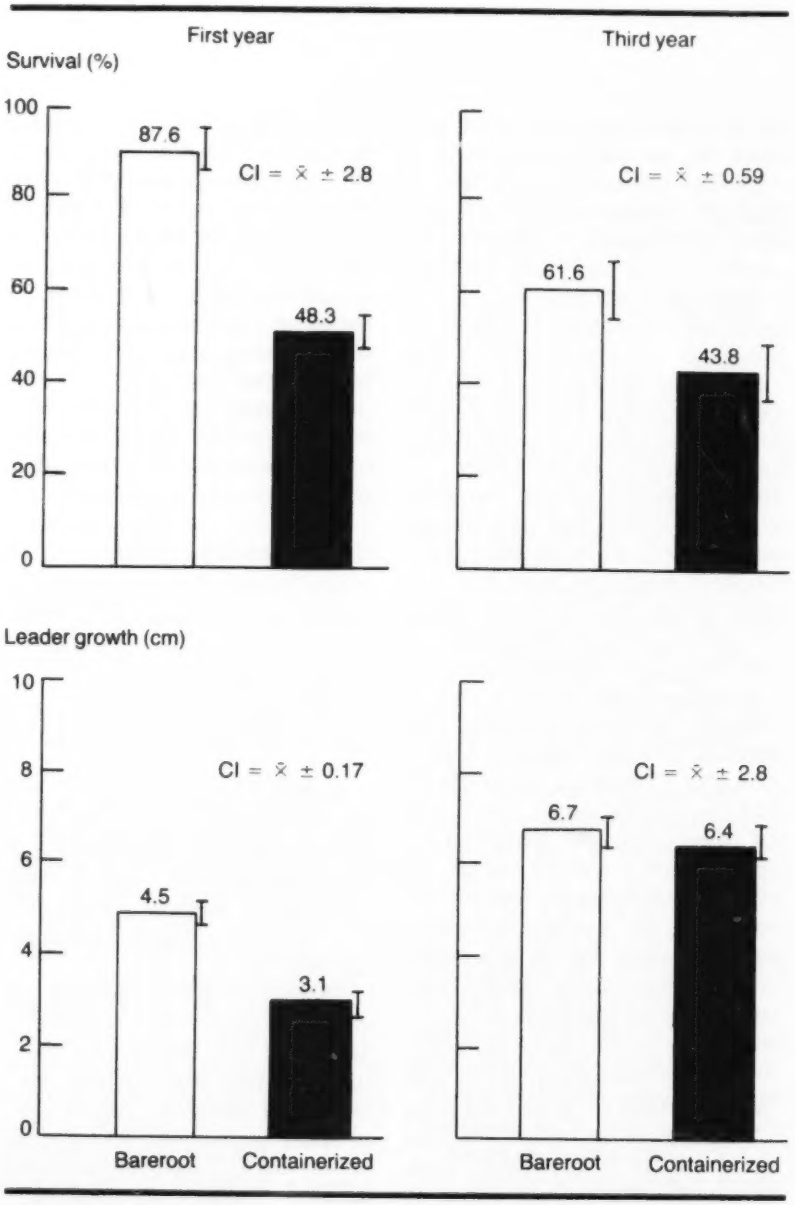

Figure 1—*Survival and growth of outplanted Douglas-fir seedlings by stock type.*

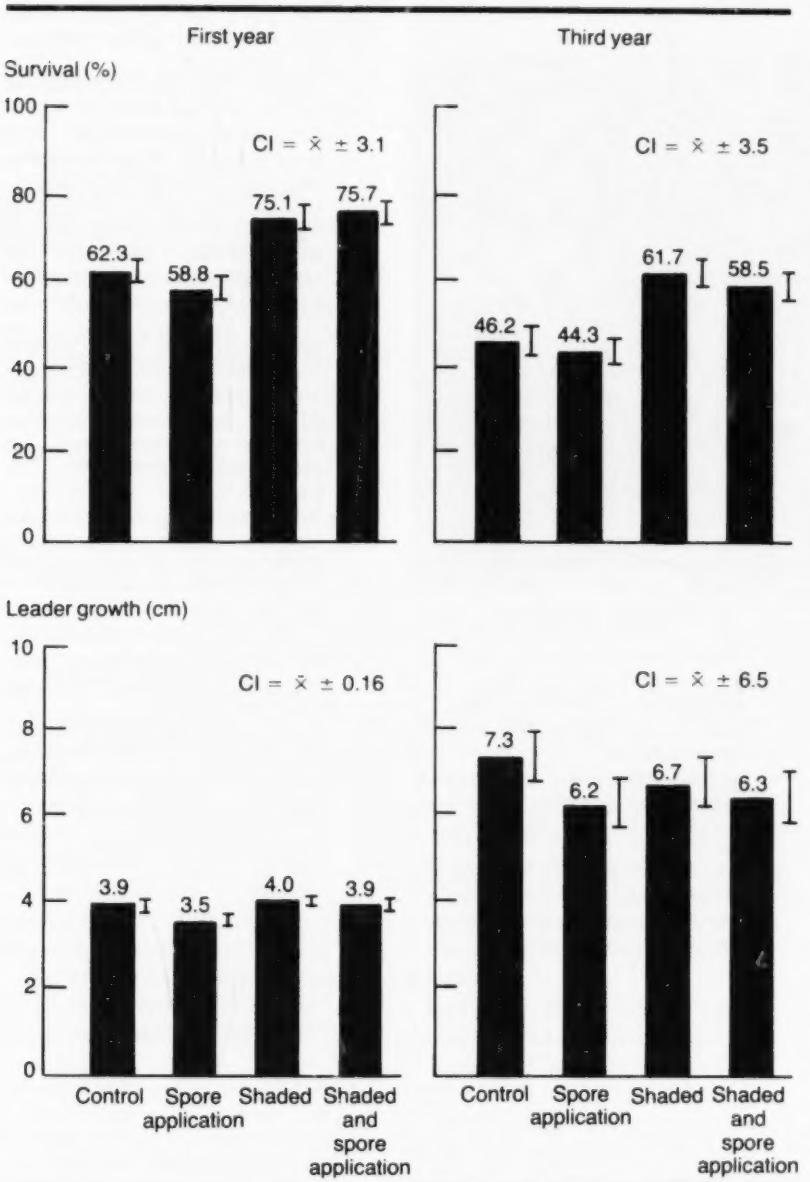

Figure 2—*Survival and growth of outplanted Douglas-fir seedlings by planting treatment.*

roots are negligible. If survival or growth could be enhanced by 1 or 2 percent, this technique could prove to be cost-effective. Further experimentation with different fungi, spore concentrations, or spore germination treatments would be worthwhile.

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Determination of Scalps per Unit Area Produced by the Bracke Scarifier[1]

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The Bracke scarifier mechanically produces scalped planting sites. Considerable error can result from small variations in planned distances between passes. The features of the scarifier and its operation are described, and a table that can be used for quick determinations of the distance between passes of the equipment is included. Tree Planters' Notes 37(4):29–30; 1986.

The Bracke scarifier (figure 1) is manufactured in Sweden and is used for approximately 70 percent of the mechanized site preparation done in that country. The equipment has been used in Canada since the early 1970's. Hand seeding in Canada with the device is discussed by Winton and Schneider *(3)*.

The Bracke was introduced to the Lake States in 1978 and its use is described by Cutler *(1)* and Nelson and Oldford *(2)*. The equipment has gained in popularity as evidenced by its use on approximately 5,000 acres in Minnesota in 1985.

The Bracke is pulled by a variety of forwarders with horsepower ranging from 90 to 210.

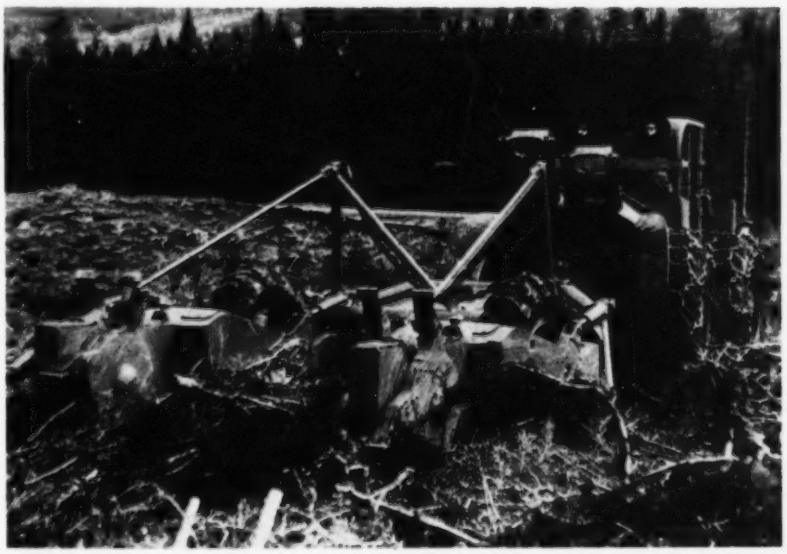

Figure 1—*The Bracke scarifier.*

The device has two scarifying wheels, each of which has four sets of scarifying teeth. The scarifying wheels are chain driven from the rubber tires on the Bracke. The scarifying teeth rotate in the same direction as the tires but turn slower so that they drag in the soil and scarify a microsite or scalp for planting or seeding.

Each pass of the scarifier produces two rows of scalps 6.6 feet (2.0 meters) apart (measured between scalp centers). Within rows, spacings of 6.6 feet (2.0 meters), 8.2 feet (2.5 meters), or 9.8 feet (3.0 meters) between scalps are possible using axle gears with 19, 17, or 15 teeth, respectively.

The Bracke is a durable machine that can be used in rugged terrain, and on relatively steep slopes, with a winch cable. It prepares intermittent scalps rather than a continuous row. This minimizes erosion because no water travel path is created. An often cited advantage with the equipment is that it lays out the planting site and increases speed and efficiency by providing a pattern that tree planters can follow. This also makes it easier for forest managers to plan and properly allocate the number of trees for planting on a unit area basis.

[1]University of Minnesota Experiment Station Science Journal Series Paper. This paper is based on work supported by the U.S. Department of Agriculture Office of Grants and Program Systems under agreement no. 85-SBIR-8-0066.

Table 1—*Scalps per unit area for various axle gear settings (which determine distance between scalp centers) and various distances between passes with the Bracke Scalper*

Distance between passes (ft)				Distance between passes (m)			
Gear 19 (6.6 ft)	Gear 17 (8.2 ft)	Gear 15 (9.8 ft)	No. of scalps/acre	Gear 19 (2.0 m)	Gear 17 (2.5 m)	Gear 15 (3.0 m)	No. of scalps/ha
27.3	20.4	15.8	400	8.2	6.1	4.7	1000
23.5	17.4	13.3	450	7.3	5.4	4.1	1100
20.4	14.9	11.3	500	6.5	4.7	3.6	1200
17.9	12.9	9.7	550	5.8	4.2	3.2	1300
15.8	11.3	8.3	600	5.2	3.8	2.8	1400
14.1	9.9	7.1	650	4.7	3.4	2.5	1500
12.6	8.7	6.1	700	4.3	3.0	2.2	1600
11.3	7.7	5.3	750	3.9	2.7	1.9	1700
10.2	6.8	4.5	800	3.6	2.5	1.7	1800
9.2	6.0	3.9	850	3.3	2.2	1.5	1900
8.3	5.3	3.3	900	3.0	2.0	1.3	2000
7.5	4.7	—	950	2.8	1.8	1.2	2100
6.8	4.1	—	1000	2.6	1.7	1.0	2200
6.1	3.6	—	1050	2.4	1.5	—	2300
5.6	3.1	—	1100	2.2	1.3	—	2400
5.0	—	—	1150	2.0	1.2	—	2500
4.5	—	—	1200	1.9	1.1	—	2600
—	—	—	—	1.7	1.0	—	2700
—	—	—	—	1.6	—	—	2800
—	—	—	—	1.5	—	—	2900
—	—	—	—	1.3	—	—	3000

The critical factor in attaining the desired number of scalps or planting spots per unit area is maintaining proper distance between passes. Table 1 provides a quick reference to determine the number of scalps that will be made with varying distances between passes. The data in the table were generated with the following assumptions.

1. A four-toothed mattock wheel is used.
2. The initial pass is made at an edge of the site.
3. Passes are longitudinal and not circular in pattern.
4. Width of a pass is measured from center to center of adjacent scalps.
5. Distance between passes is measured from center to center of scalps on outside rows.
6. All scalps are plantable.

Maintaining the proper distance between passes is difficult under field conditions. However, even small variations in distance between passes can result in considerable error in number of scalps per unit area. For example, a variation of 1 foot between passes results in a difference of about 50 scalps per acre (table 1). Similarly, one-third of a meter variation in distance results in a difference of more than 100 scalps per hectare. In order to calculate the number of trees needed for planting, the operator and landowner should determine the average spacing between passes and assess the number of plantable scalps, which may vary with site conditions.

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